TROPICAL BIOLOGY

J. YANNEY EWUSIE

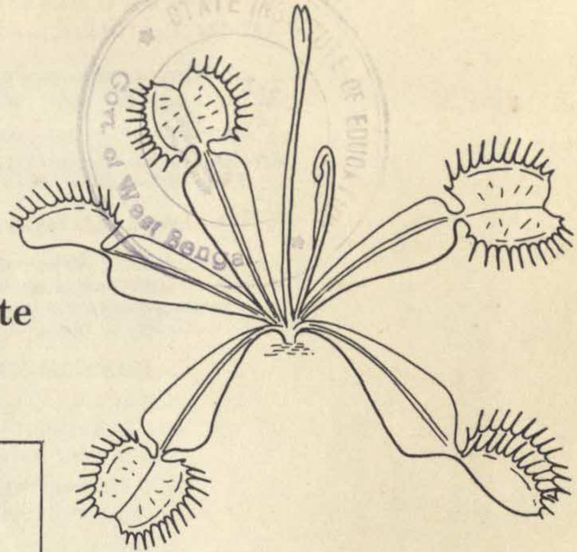
TROPICAL BIOLOGY

By the same author

TROPICAL BIOLOGICAL DRAWINGS

TROPICAL BIOLOGY

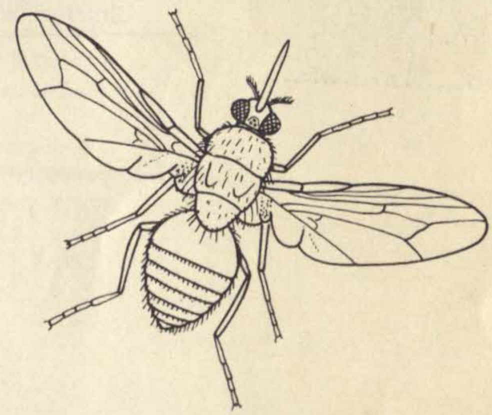
For 'O' level & School Certificate



by

J. YANNEY EWUSIE

B.Sc. (Lond.) Ph.D.(Cantab.) M.I.Biol. F.L.S. F.G.A. F.W.A.
Professor of Botany, University of Cape Coast



Third Edition, Revised and Enlarged 1974

HARRAP LONDON

First published in Great Britain 1964
by GEORGE G. HARRAP & CO. LTD
182–184 High Holborn, London WC1V 7AX

Reprinted with amendments 1964
Reprinted: 1964; 1965; 1966
Second edition, revised and enlarged, 1968
Reprinted: 1968; 1969 (twice); 1970; 1971; 1973
Third edition, revised and enlarged, 1974

ISBN 0 245 52325 1

Cover photographs by Paul Brierley
'Starfish' and 'Tropical Iris'

Printed by Pitman Press, Bath
MADE IN GREAT BRITAIN

Preface

BIOLOGY text-books were first written in temperate countries, and for some time they have been used in tropical countries even though in many cases the organisms described in such books are foreign to the tropics. Some of the organisms are strictly temperate creatures and cannot be made to thrive in the tropical weather, others can be introduced only into parts of a tropical country, and finally even where one could thrive in all parts of a tropical country, it may not be readily available to the schools situated in remote parts of the country. Moreover, the introduced plant or animal may have no acceptable place in the tradition of the local people, and if it is useful, it is often only cultivated by residents from temperate countries. Nor does the use of preserved specimens do justice to the study of biology. Above all, the tropical flora and fauna are even richer than the temperate ones, and equally good substitutes for the temperate specimens can be found in the tropics. It is true that some of the tropical examples provided in syllabuses were at first not as well understood as the temperate ones, but this position has now changed, and students in the tropics can have the basic information to enable them to study the organisms around them.

The present book is specially written with the tropical modifications of School Certificate syllabuses in mind. Where the information is unavailable or contradictory in the literature, I have made my own observations and experiments. Throughout, I have emphasized that it is essential to cultivate careful observation, accurate description, and experimentation in scientific training.

If this book helps students in tropical countries to appreciate the biology of their environment and to acquire a basic scientific approach to their problems, then the time and energy spent in producing it will not have been wasted.

J. Y. E.

Cape Coast, Ghana

Note to the Second Edition

BIOLOGY FOR TROPICAL SCHOOLS is already well known and widely used. This new edition incorporates more material designed to meet some of the current problems in tropical countries.

Ecology is becoming an increasingly important subject and this chapter is now given greater weight, with particular emphasis on aspects of conservation and land management. The new section dealing with nutrition includes a detailed treatment of practical problems of diet, for both man and his livestock.

These and other detailed changes ensure that *Biology for Tropical Schools* will continue to be an up-to-date textbook for use in tropical countries.

Note to the Third Edition

I HAVE taken the opportunity of this new edition, not only to broaden the contents of the chapter on ecology, but also to add a chapter on heredity. Most of the drawings in this edition have been redrawn and the book has been redesigned to make it more attractive and readable for students. The book is thus brought abreast with the growing trends in biology.

Acknowledgments

A NUMBER of persons have been most helpful to me in the preparation of this book, and it is only proper that I take this opportunity to express my gratitude to them. First among these is the artist of the Department of Botany, University of Ghana, Mr. S. K. Avumatsodo, who advised me about the drawings and inked nearly all of them for me. I also thank Mr. Moses Diego, my laboratory assistant, for stencilling the labels on the drawings and Mr. A. A. Osekre for typing the manuscript. I also received some helpful advice early on in the preparation of the script from Mr. D. Morgan, formerly of Adisadel College, Cape Coast, Ghana, and Professor of Botany at the University College, Roma, Basutoland, now in the Institute of Science Education, Kumasi, Ghana. Mr. Peter Dixon, formerly mycologist in the Botany Department of the University of Ghana, assisted me with the description of *Rhizopus* and *Penicillium*. This list will not be complete without mentioning Mrs. S. M. Haggis, Senior Science Mistress at Mfantsipim School, Cape Coast, Ghana, and now at the Institute of Education, Legon, Ghana, for originally suggesting to the publishers that I could be persuaded to undertake this work. Among my personal friends who have spent their time discussing various aspects of this work are Mr. V. Ammah-Attoh and Mr. T. K. Tewiah, and I am very grateful to them.

Now I should express my indebtedness to the authors and publishers who gave me permission to use some of their illustrations as shown here: for Figs. 1.1, 6.2, 10.9, 18.3, 19.3, 20.1, and 26.6 from *A Biology for the West Indies and British Guiana* by V. Graham (Macmillan, 1956); for Figs. 6.6 and 6.9 from *Animal Life in the Tropics* by E. M. P. Walters (Allen and Unwin, 1960); for Figs. 10.1 and 10.8 from *General Zoology* by T. I. Storer and R. L. Usinger (McGraw-Hill Book Company, Inc., 3rd edn. 1957); for Fig. 17.1 from *A School Course of Biology* by J. Hunter (Longmans, Green, 2nd edn. 1938); and finally for Fig. 24.6 from *The Plant Kingdom* by W. H. Brown (Ginn & Co., U.S.A.). I would also like to thank Mr. K. G. Farrall for the many illustrations he has drawn for this edition.

Contents

PART ONE

CHAPTER ONE

Biology—The Study of Living Things

BIOLOGY is the study of living things. The word 'biology' comes from two Greek works, *bios*, meaning life, and *logos*, reasoning. It is a branch of science which deals with structure, internal functioning, development, processes of maintaining life, behaviour—in fact all matters concerning all living things, including human beings.

To begin with, it is worth examining how living things really differ from non-living things such as pieces of stone or iron. This is not always as easy as it appears at first sight. For example, the eggs of some animals, or the dormant seeds of plants, often do not show much sign of being alive unless placed in favourable conditions. The main differences are as follows:

1. **Form and Size.** A living organism usually has a definite form and a characteristic size (within certain limits). Thus any coconut tree, humming-bird or whale is very much the same size and shape as any other of its kind. Non-living things, on the other hand, vary widely in such respects. For example, there is no one form and size for a mountain, a river, or a flame.
2. **Structure.** The parts of a living organism are composed of microscopic units called *cells*. These are assembled together into various groups for performing the life processes. Cells contain a living substance known as *protoplasm* (see below). Non-living things are not made up of cells. For instance, any structure which rocks may have varies with their constituents or how they have been formed
3. **Nutrition.** Every living organism takes in food substances from outside. Where necessary, these substances are changed by *digestion* into forms which can be absorbed or *assimilated* by the organism. Finally, they become part of its body and may form the source of the energy which it needs for its various activities. Non-living things do not feed.
4. **Respiration.** During respiration, oxygen is taken in from the air (or water) by the organism and is used to break down assimilated food, thus releasing energy for use by the organism. As a result of the breaking-down process, carbon dioxide is produced. Non-living things do not respire.
5. **Excretion.** Waste products accumulate inside living things as a result of respiration and other vital processes. These products have to be removed from the body—that is, *excreted*—if the organism is to remain healthy. Plants and animals also control the loss of water vapour and gases. Non-living things do not excrete, neither do they control the loss of water vapour and gases.
6. **Secretion.** Various parts of the living organism produce, or secrete, certain useful substances. For example, when we digest our food, *glands* secrete special substances known as *enzymes* which are needed for the digestive process. Non-living things do not secrete any such substances.

7. **Growth and Life-cycle.** Living organisms grow and maintain their size as a result of feeding. The increase in size takes place by development of new tissues between or within older ones and by the replacement of parts of the body. Living organisms also have a definite life-cycle consisting of birth, growth, maturity, old age and death. Non-living things do not grow and have no life-cycle. Sometimes a non-living thing may appear to grow. Alum crystals in a solution of alum increase in size and stalagmites lengthen in caves. However, they do so by external addition and there is no orderly cycle of change.
8. **Reproduction.** Every living organism is capable of reproducing more organisms like itself. Non-living things cannot reproduce.
9. **Irritability** (response to stimuli). Living things can react to changes outside or inside themselves. If they do, they are said to be *stimulated* and the changes are called *stimuli* (plural of *stimulus*). The *response* given by the living thing may be movement of part of the stationary organism, like a flower turning towards the sun or a movement of the whole body from place to place (*locomotion*), like an animal avoiding danger. The extent of the response need not be proportional to the strength of the stimulus used and the state of the organism is not necessarily altered permanently by the stimulus. Non-living things do not normally respond to stimuli. When they do, the extent of the response is proportional to the stimulus and the object may undergo a permanent change. For example, when ice is heated it soon changes into water and the amount of ice melted depends on the quantity of heat used.

   The activities and changes that take place in the living body make up what is called *metabolism*. These include the processes of nutrition, respiration, excretion and secretion. Some of them, such as nutrition, are building-up processes and are called *anabolism*. Others, such as respiration and excretion, are breaking-down processes and are referred to as *katabolism*. For growth to take place, anabolism must exceed katabolism.

Protoplasm—The Source of Life

All living things are alike in that they carry out functions of the kind mentioned above. Do they also have a structure in common? To some extent, they do. They are all made up of a complex jelly-like substance, much like the white of an egg, called *protoplasm*. This is the basis of all life. The protoplasm in a living organism is continually active and this activity does not stop until life ceases.

Chemical analysis reveals that protoplasm largely consists of water and some mineral salts, but also contains varying amounts of proteins, sugars and fats, which are products of metabolism. All the components of protoplasm are made up of the relatively familiar elements, carbon, hydrogen, oxygen and nitrogen in various but definite proportions, together with small traces of phosphorus, sulphur, calcium and other elements. This shows that protoplasm, or the 'physical basis of life', does not contain any extraordinary substance. It is true that the proteins which are its main solid constituents are very complex in chemical

structure, but it is not these alone which provide the basis of life. Living protoplasm is also maintained by its constant reactions in response to the environment. In fact, protoplasm shows all the characteristics of living things already mentioned.

If protoplasm is the basis of life, then new life can arise from older protoplasm; in other words life as we know it today may have arisen from pre-existing life. The process by which new life is formed is termed reproduction, as we have already mentioned. When we come to discuss the details of this in a number of living organisms we shall find that very often each of the two parents contributes a cell which is highly charged with protoplasm. These cells fuse together to form the new protoplasm of the offspring. We notice that children resemble their parents. This similarity is mainly due to the contents of the particular protoplasm contributed by their parents to form the new protoplasm of the young one. The study of how characteristics pass from one generation to another is called *heredity*. *Genetics* is the study of the mechanism of heredity and variation (see Chapter 33).

As all living things consist of protoplasm and have a number of similarities, some of which we have already enumerated, there is reason to believe that they are to some extent related to each other. They must therefore have been derived from one or more common ancestors, changing or *evolving* in this process. We shall introduce and illustrate the evidence supporting this belief at relevant points in this course as we describe some of the different types of plants and animals. This concept of the *evolution* of living things is now generally accepted in biology and its study is called *organic evolution*.

Scope and Purpose of Biological Studies

We have just mentioned two branches of biology—genetics and organic evolution. It is now worth introducing the other branches. When we begin to study any organism we first describe it and the description of the external features is called *morphology*. But our description is not complete unless we include some account of the internal structure, which means we must cut up the organism. This study is *anatomy*. Also we can study the internal activities of the living organism by physical and chemical methods. Such a study is termed *physiology*. All these methods of study are used to follow the development of the organism from its earliest stages, as well as to describe the adult.

Apart from the study of individual organisms we sometimes wish to learn about groups of the same or different organisms in their natural surroundings, finding out how they are distributed and how they react to the environment. Such a study is termed *ecology*. Studies concerning habits, life-histories and adaptations for survival and reproduction constitute *natural history*.

These are the main branches of biology with which we shall be concerned in this course. It is clear from these that biology is more than nature study, which consists mainly of descriptions and general observations in the field.

You may ask at this stage why it is necessary to study biology. In the first place, why do we study at all? Firstly, the study of any subject

stimulates and disciplines the mind. Secondly, biology as a science develops our powers of accurate observation and provides us with a framework into which our observed facts can be fitted. Thirdly, the study of biology can make us more appreciative of the fact that all living things are somehow related, not specially created (see Fig. 1.1). Thus biological studies of even very simple organisms can help us to understand ourselves more fully. Fourthly, through biological knowledge we are able to understand more clearly factors affecting our survival, such as drugs and sanitation for our health, food requirements and methods of increasing food production and various other products for our shelter and comfort. Lastly, perhaps, the study of biology stimulates our interest in the lives of other animals and plants and increases our enjoyment of our surroundings.

On the whole, the benefits of biological studies are far-reaching and even the destinies of nations have been at stake when biological knowledge was scanty. For example, the construction of the Panama Canal almost came to a standstill because of yellow fever, and could only be resumed when the physiology of the mosquito which carried the disease had been studied and ways of controlling it had been found. Another such example is West Africa, where malaria, again caused by the mosquito, made white settlement difficult for many years because the biology of the mosquito was not well understood. Greater knowledge of the ecology of the mosquito helped the achievement of independence by the territories by enabling their resources to be economically developed.

Plants and Animals

The two principal groups of living organisms are plants and animals. While they all show the various characteristics of living things listed above, plants differ from animals in certain ways. No doubt everyone feels confident that when he sees different types of plants and animals he can name some of the differences between them. For example, it is not difficult to see that animals have compact bodies, are active and are aware of their surroundings through senses such as sight, hearing, touch, taste and smell, whereas plants are usually branched, green and virtually incapable of moving from one place to another.

These differences are clear from everyday observations. However, these observations are based almost entirely on the large and conspicuous higher animals and plants and will, in fact, have to be modified. On the one hand, they do not quite fit the lowest and smallest living organisms, while on the other, they ignore the most important difference, which is the mode of nutrition.

The invention of the microscope enabled biologists to discover the many plants and animals which cannot be seen with the naked eye. Some of these microscopic organisms do not fit very well into the classification of the obvious differences between plants and animals just mentioned.

For example, there are certain minute animals which behave like plants; some are green (such as *Euglena*), others grow in branched

colonies (for example, *Obelia*) and still others are stationary or fixed (for example, sponges, sea-anemones and barnacles). Conversely, certain minute plants behave like animals by swimming actively—for example, *Chlamydomonas*—and some others are not even green—for instance, the fungi. We shall deal with some of these in detail later. It is not surprising that some organisms appear to be intermediate in character between plants and animals, since the classification is of our own making.

We now come to consider what is, in fact, the fundamental difference between plants and animals, one which could not be detected from a study of structure (morphology or anatomy), nor understood until biologists were able to study the physiology of living organisms, particularly of plants. This is the mode of obtaining food. Plants do not take in chemically complicated food as animals do. Instead, they

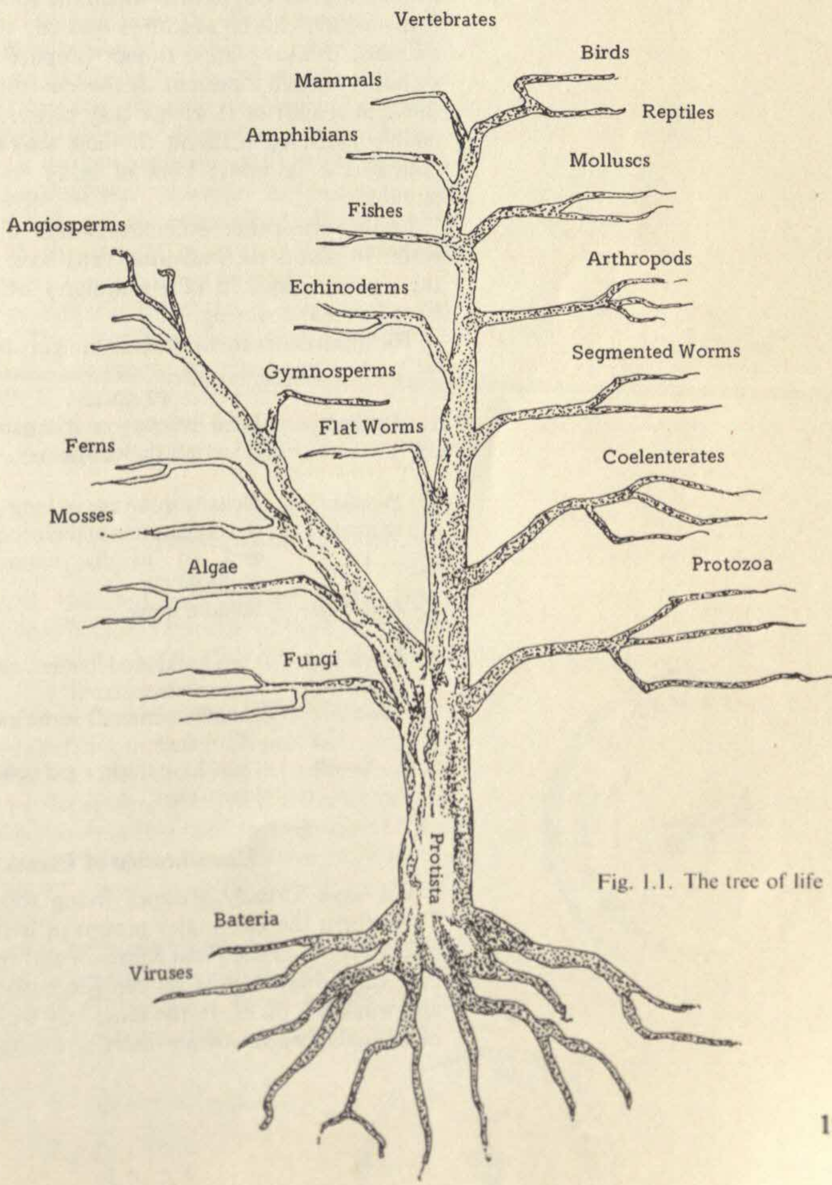


Fig. 1.1. The tree of life

build up their own food from simple substances, water and carbon dioxide. These are utilized by plants in the presence of light and usually with the aid of the green colouring matter in the cells of plants. This green matter, called *chlorophyll*, enables plants to absorb and use sunlight as a source of energy for building up food. However, a few minute plants which have no chlorophyll use chemical energy for preparing food.

This basic difference between plants and animals enables us to understand a number of the other differences already mentioned. Thus, since plants make their own food from sources that are available in their normal environment, they can remain stationary. By being branched, they provide a larger surface through which carbon dioxide penetrates by diffusion. Among animals, on the other hand, chemically complicated organic food is taken in and there is need for a mouth as well as for a digestive system in which the food is broken down into simpler forms which can be absorbed into the cells of the body. Again, since animals, unlike plants, cannot prepare their food from simple substances normally present in the environment, they must be able to move in search of it. Hence they possess organs for movement which enable them to respond to their surroundings. For movement, of course, the compact kind of body found among animals is most suitable.

Lastly, one other difference worth mentioning is that of the cell-walls. In plants the individual cells have cellulose walls which provide the rigidity required of a stationary object, but in animals the cells have no such covering.

The differences mentioned so far may be set out as in the table below.

	PLANTS	ANIMALS
1. *Feeding*	Feed chiefly on inorganic materials (holophytic)	Feed on living or dead plants or other animals (holozoic)
2. *Preparation of food*	Usually make use of light in the preparation of their food and so usually contain chlorophyll	Do not usually use sunlight in the process of feeding. Rarely contain chlorophyll
3. *Irritability*	Seldom move	Usually move and respond quickly to stimuli
4. *Form and Structure*	Have branched bodies and organs are external	Have compact bodies and organs are internal
5. *Growth*	Usually terminal (at the end of organs)	Growth at various parts of body
6. *Cell-wall*	Cells have thick, rigid cellulose walls	Cells have only delicate membranes as walls

Classification of Plants and Animals

We have already grouped living things into plants and animals. These form the two major groups of living organisms, and we usually refer to them as the *Plant Kingdom* and the *Animal Kingdom*. From our everyday observations we can generally recognize what is an animal and what is a plant. In the same way we know of many different kinds of animals: we know an insect, a fish, a toad, a bird and a mammal

such as the dog, the cat or the monkey. All these form different groups of animals and we readily know that each group differs in its own way from the other group. We often have local names for these groups. But if we take any one of these groups and examine it further, we shall find that it is possible to distinguish various types of animals forming that group. Let us take the monkey as an example. There are several types of monkeys—the *colobus* in Africa, the *nasalis* or *proboscis* monkey in Borneo, the *langur* in India, the *baboon* and *mandrill* and the *macaque* or *rhesus* monkey of Asia, which is much used as a pet and in biological research. Similarly, different types of animals can be found in any of the other groups mentioned above. In the same way the members of a group in the Plant Kingdom can be classified.

Now, in different countries different common names may be used for the same animal or plant. For example, the common tropical weed known as the blue fleabane in the West Indies is known in Ceylon as *chitiviyarchen kanir*, in India as *kuk-shma* or *kukur-songa*, and in Nigeria as *tenoreana*. This difficulty was realized later, when man first started to observe animals and plants and to compare the common names given to each one of them in different countries. For many years it was not easy to solve this problem. However, Latin was then the universal language of the educated, and in the eighteenth century a biologist called Linnaeus proposed that it would be easier for all nations to refer to the same animal or plant if they all adopted a double Latin name for each type. In this way it did not matter what common or local name was used for the particular animal or plant.

The first of the two Latin names was called the *generic* name, and the second the *specific* name. This system of using two Latin names was called the binominal system. The generic or tribal name was given to all plants or animals which had many characteristics in common, while the second, specific, name was given to each particular type, describing the special characteristics making it different from the others in the same tribe.

An example in the Animal Kingdom is the cat tribe or genus which was given the name *Felis*, and each of the animals within this tribe was also given a special second name or species name. Thus the domestic cat was named *Felis domestica*; the wild cat, *Felis catus*; the tiger, *Felis tigris*; and the lion, *Felis leo*. It should be noticed that the generic name always commences with a capital letter while the specific name begins with a small letter.

Let us now consider an example from the Plant Kingdom. We all agree that the sweet orange, grapefruit, lime, lemon and tangerine are very similar in many respects. Yet they differ sufficiently for us to recognize each of them. All of them were given the tribe or generic name *Citrus* to which a specific name was added in each case to distinguish the various types. Thus the sweet orange is *Citrus sinensis*; the grapefruit, *C. paradisi*; lemon, *C. limon*; lime, *C. aurantiifolia*; and tangerine, *C. reticulata*.

Just as some different species, such as those we have mentioned, have been found to be sufficiently similar to be grouped together into one genus, so a number of genera (the plural form of genus) are grouped together into a family. For instance, there are the Compositae

(the sunflower family), the Papilionaceae (the pea family), and the Malvaceae (hibiscus family). The genera within one family resemble one another in the arrangement of their flowers, their anatomy and other features. The process of regrouping often goes still further. Thus fairly similar families may be grouped together to form an order.

Since we shall really be dealing with individual animals and plants in this book, it is not necessary to go any further with the higher groups of families and orders. However, it is worth knowing the principles involved because casual references to such groups may be found throughout the book. The genus and species names are enough for a plant or an animal at this stage of the course, and even these will normally be used only where no common name exists or where various common names are used for a particular plant or animal in different tropical countries. The binominal name is then essential to avoid confusion.

Trends of Evolution in Plants and Animals

We have learnt that in both plants and animals any species which are similar may be grouped together into a genus, and the genera with similar characters may also be grouped into families, and families into orders and so on. This process of classification enables us to picture the major groups of plants and animals. We find that there are many degrees of complexity in the groups. For example, in the Animal Kingdom there are groups made up of organisms in which the whole body appears to consist of a single cell (like *Amoeba* or *Paramecium*). In another group, the body of the organism is made up of many cells but the cells are not very specialized (as in *Hydra*). Highly specialized cells are found in groups like insects, fishes, amphibians, reptiles, birds and mammals. Without going into a long discussion, we can understand that there are several groups of animals with different degrees of complexity of structure and physiology, ranging from the apparently simple, single-cell animal like *Amoeba* to the highly complex mammal, Man. This increasing complexity may be regarded as a trend of evolution in animals.

The same can be said with regard to the Plant Kingdom where we begin with apparently simple-celled forms like *Chlamydomonas*; we then come to slightly more complex plants like *Spirogyra* and other small plants with no proper roots (like the mosses and liverworts); then come bigger plants like ferns, followed by plants like *Cycas* which are more advanced but do not have true flowers and ovaries, examples of which are the hibiscus, the coconut and the mango. Generally, the simpler or 'lower' organisms are said to be primitive while the more complex or 'higher' ones are said to be advanced.

It is very useful to bear this picture of the trend of evolution in mind, as it is the order used in this book with respect to the animals and plants we have to consider.

SUGGESTED PRACTICAL WORK

1. *Respiration.* This is one of the important characteristics of living things. It is shown by the absorption of oxygen and the release of carbon dioxide. Thus we can use this principle to show that the soil contains micro-organisms.

Set up the apparatus in Fig. 1.2 as follows: place a lump of soil inside a large bottle, and stand a beaker of clear lime-water by it. Cork the bottle and put it in a dark place. After some time the lime-water turns milky, showing that carbon dioxide has been produced by the organisms in the soil. Remove the cork from the bottle and bring a lighted taper to the mouth of it. If the taper fails to burn, the oxygen has been used up during respiration. If the experiment is repeated with soil which has been baked and sterilized (as a control) then no carbon dioxide is produced.

2. *Growth.* (*a*) Non-living things do not grow. Suspend a crystal of alum in a saturated solution of alum, and note the size of the crystal from time to time. After some hours it is found that more crystal has been formed on the surface of the original one. This increase in size is not growth of the kind that occurs in living things, because the new parts are formed only on the outside.

(*b*) Now observe what is real growth in living things. Your teacher will give you a 4-year-old maize or other seedling. Measure the height of the coleoptile every 24 hours for 3 days.

3. *Protoplasm.* Remove a stamen from the flower of *Tradescantia* and examine it carefully. Now pluck a few hairs from the stamen and mount them on a glass slide. Examine this slide under the microscope and pay particular attention to the protoplasm of the cells. Is the protoplasm in active motion?

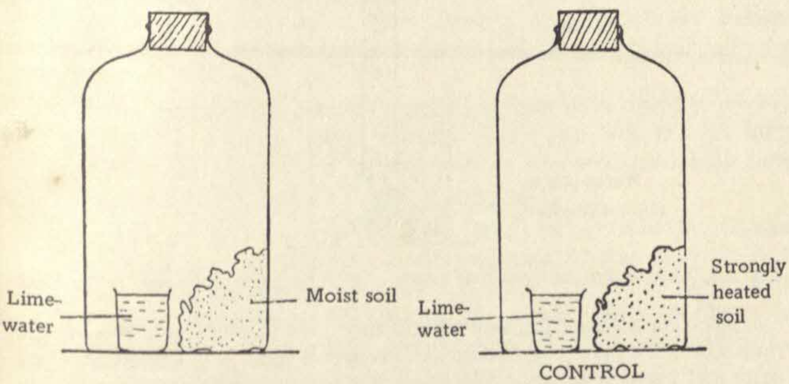


Fig. 1.2. Experiment to show that the soil contains micro-organisms

Take another stamen and kill it by immersion in boiling water for a short time. Mount some dead hairs and examine in the same way. Has the protoplasm undergone any visible change in its behaviour?

4. *Photosynthesis.* Green plants can make their own food when provided with the simple raw materials of carbon dioxide, water, and light. This process is called photosynthesis and one of the end-products of photosynthesis (as well as food) is the gas, oxygen. It is possible to demonstrate that green plants give out oxygen by performing the following experiment:

(*a*) *Apparatus.* Use a funnel with a large diameter (6 cm to 7½ cm) and a short stem. Invert it into a large beaker of water and enclose some plant

material beneath the funnel; place a test-tube filled with water over the stem of the funnel (Fig. 1.3). It is best to set up this apparatus in a bucket of water and then lift it out and insert some small pieces of stone beneath the funnel rim. In this way, free circulation of water occurs around the plant in the funnel. Ensure that each set of apparatus contains the same amounts of water-plant and solution. Explain why this is necessary.

(*b*) *Water precautions*. Best results will be obtained if rain water or boiled water is used. Ordinary tap water usually contains dissolved air and this tends to collect round the sides of the glass apparatus when exposed to sunlight.

(*c*) *Plant material*. Almost any thin-leaved plant can be used, and it is suggested that a number of demonstrations be set up using plants with different types of leaves. It is sometimes found that plants with very finely divided leaves are not suitable for use in this experiment since bubbles become trapped in the leaflets.

(*d*) *Carbon dioxide*. The water used in this experiment should be enriched with carbon dioxide; this can be done by bubbling the gas directly into the water for some time or, alternatively, by adding some soda water from a siphon to the water in the beaker.

(*e*) *Light*. Direct sunlight should be allowed to fall on the apparatus, which should be set up in a prominent position in the open air. Other sets of apparatus could be set up in other situations at the same time—for example, in the shade, under a bright electric lamp and in a totally dark cupboard. It will be interesting to compare the results obtained after a fixed time.

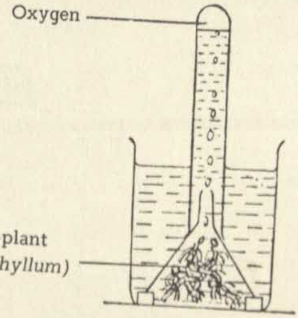


Fig. 1.3. Experiment to show that plants give out oxygen when they make food

(*f*) *Test for oxygen*. Remove the test-tube very carefully, first placing the thumb over the open end of the tube. Prepare a splint with a finely tapering point and allow it to smoulder. Insert the splint into the test-tube, taking care that it does not touch the wet sides of the tube. If oxygen is present in the tube, the splint will glow brightly and it may burn with a small flame.

5. *Classification*. What is the local name for the pepper? (This may be a genus name.) Now what do you call the small type of pepper often eaten and spread by birds? This type of pepper is a different species from the ordinary finger-like pepper. What do you call the latter? We have here two species belonging to the same genus.

CHAPTER TWO

Ecology: Relationships of Living Things with Their Environment and Among Themselves

ECOLOGY is the study of all the relationships that exist among living organisms and between living organisms and their environmental factors. Ecology helps us to understand nature and in particular to find out how organisms live and behave in their normal surroundings and how they succeed in surviving from generation to generation. In order to get the necessary facts it is often not enough merely to observe what exists in nature, but it is important to conduct experiments in the field, in the laboratory or in both.

Ecology has become an important subject in the advanced countries because of the unfavourable effects of industrialization on the vegetation, rivers and the air. Newly emerging and developing countries in which rapid development is making heavy demands on the large untapped natural resources need to avoid the mishaps now facing a number of developed countries. The more we know about the ecology of our resources the better we shall be able to solve problems about them.

Among the present and future problems which ecology can help us to solve are the following:

(*a*) Land use and management.

(*b*) Establishment of a more healthy and long-term balance between both wild and domestic plants and animals in their environments.

It is important to ascertain before certain development projects are started, what possible harmful effects can follow such interference with the natural populations in the area and how these effects can be prevented or at least controlled.

(*c*) Proper treatment of the great variety of communities of areas like the forests, grasslands, standing or running waters or the soils. This will enable man to learn not to destroy any part of nature without giving thought to the future. He would learn to obtain his requirements at such a rate that the normal balance in that part of nature is not permanently jeopardized.

(*d*) Better control of the spread of pests and diseases, not only as affecting man, but also among domestic animals as well as field and stored agricultural crops.

Levels of Ecological Studies

The portion of the earth in which living organisms exist is what the ecologist is concerned about. This portion of the earth consisting of the air, water and the soil and which is inhabited by living organisms is referred to as the *biosphere*. As is well known, water forms a greater part of the surface of the earth than land. In general, conditions in water everywhere are similar, and so are conditions on land. This is

due to similar environmental factors. Areas with similar environmental factors and which sustain life form a similar *habitat*. Thus on the basis of the above, we can speak of aquatic (water) and terrestrial (land) habitats as among the broadest subdivisions of the biosphere. Further subdivisions can give us the marine, the freshwater, the montane or the arboreal habitats. The term habitat may also be used for even smaller portions of the habitats named above. Indeed, in general usage a habitat may simply mean the locality (with its characteristic environmental factors) in which the organisms under study are living.

Most habitats that one may choose to study would consist of different kinds (or species) of plants or animals or both. Such a collection of numbers of different kinds of organisms is considered as forming a *community*. Thus when we wish to study a community we have to deal with the essential aspects of each of the species present.

We may on the other hand wish to study the ecology of only one of the different kinds or species in a community. Here we consider the group of that species as constituting a *population*. A population thus consists of a group of individuals of a single kind or species of organism. We can now see that a community can be regarded as consisting of a mixture of different populations.

Although it is possible to limit the study of a habitat to the entire community or to a particular population within it these studies by themselves can at best only give us a picture of the structure of the habitat. They give us no indication as to how the community or its function in the habitat nor how the environmental factors are also affected by the organisms in the community. It is therefore necessary to include a study of the non-living or physical environmental factors in a complete ecological study of a community or a population. The ultimate picture is thus given by how the community and its non-living environmental factors function together. This picture is then seen as an ecological system referred to as an *ecosystem*. This realization has shown that the ecosystem is not only the basic unit of ecology but also the highest level of organization in ecology. The ecosystem concept enables us to appreciate the role of each part of the system, such as, for example, how energy is transferred from one part of the community to another in the habitat.

Special Features of Tropical Ecology

It is necessary here to draw attention to some of the special features of tropical ecology. The fact that temperatures are relatively high throughout the year in the tropics means (*a*) that plants and animals must have evolved adaptations to the high temperature, (*b*) that rapid loss of water, and hence water shortage is a problem in many parts (except in the tropical rain forest), (*c*) that climatic factors like rainfall play a significant role in the life of the plants and animals, and (*d*) that decomposition of dead plant and animal materials is relatively rapid.

Also the flora and fauna are generally luxuriant throughout the year because (except for the hot deserts) there is no harsh period like the winter of the temperate climates. As such different species of plants flower at different times throughout the year and a number of tree

species even flower more than once a year, so also do different kinds of organisms reproduce at almost every time during the year.

Again unlike temperate organisms, tropical organisms seem to contain too many types (or species) of organisms.

Finally despite the seeming monotony, the tropics appear to provide more varied habitats than are found in temperate climates.

How a Community Develops and Functions

The best way to study how a community of plants and animals starts and how it grows to its more or less permanent form is to study how organisms begin to invade a fresh area that has not had any vegetation or animals before. Common examples are alluvial deposit sites, soil-surface exposed after a landslide, a bare rock, a newly felled tree trunk, or fresh standing water.

If the area has no soil already, such as a bare rock surface, then the first action that takes place is the weathering of the rock surface by forces of nature (such as the heat of the sun, the rain and wind) to form the beginnings of soil. In the development of the community the first living organisms to appear at the site are referred to as the *pioneers*. These are often microscopic algae and some mosses, but on bare rock we often find lichens before the algae and mosses. This is because lichens are more able to live in the very harsh conditions on the rock. It should be mentioned here, however, that some higher plants may be among the pioneers carried by the wind and by animals like birds. The pioneers survive more in the crevices in view of the increased drying effect of the high temperature. As the pioneers live and die they add their remains to the soil. This creates conditions that are more suitable for other plants which could not live there at first. These new entrants are often annual flowering herbs and some ferns, as well as some lower animals. As they also live and die their remains improve the soil conditions further, and so perennial herbs including grasses are able to grow there too. As this happens the pioneers die off as the condition of the area is no longer suitable for them. The process continues, and as soon as a point is reached at which the soil can support the growth of taller species, then shrubs and trees begin to enter the habitat and grow. Some higher animals may also be found at this stage. It should be mentioned that in the tropics the number of different kinds of plants and animals increases as this process goes on.

When this happens the taller plants begin to shade out some of the lower plants which may eventually die out. But the shade loving plants survive, and more of such plants continue to grow in the shade. The taller trees thus modify the local climatic conditions for the plants beneath them and by such action they are said to be the dominant plants in the community. In the tropics many kinds (species) of plants form the dominant group in the community.

This process described in brief above, whereby the same area is inhabited by a series of plant and animal organisms until a virtually stable community is formed is referred to as *succession*.

It should, however, be stressed that the actual series of organisms and the rate of development of the community depend on a number of

factors including: (*a*) the type of pioneers and other plants that are available in the vicinity of the area in question, (*b*) how suitable the area in question is for those plants that get there, (*c*) how far the successive organisms are able to modify the soil and other factors of the environment and (*d*) what is the nature of the original surface of the habitat, that is how dry or wet it is.

On this score it should be pointed out that the description of succession given above is typical of succession on land and it can be observed that the succession results in increasing retention of water in the soil.

In contrast to this, succession in water proceeds by filling up the water and bringing the habitat to near land conditions. Thus, in this case the soil gets drier and better aerated as succession proceeds. Succession in water therefore results in the disappearance of the water and the substitution of land conditions.

It is possible to observe what would appear to be succession in habitats that seem to run parallel to each other. These illustrate *zonation*. Thus on sand-dunes for example one may notice different stages which look like stages in succession starting from the edge of the sea waves with marine plants and animals to normal land conditions with normal land plants and animals. Careful observation also shows a similar arrangement around standing water or even on the banks of running water particularly in relatively drier vegetation like the savannas. The typical pattern here is to have water-plants near the water, water-loving land plants next, and then normal (dry) land plants further away from the water.

Food Relations in an Ecosystem

As already pointed out plants, animals and the physical factors in an ecosystem exert various effects on each other. One of the ways of illustrating this is to examine the food relations of the different types of plants and animals in the community. Such a study shows that a typical community has three basic categories of organisms which function at three broad levels as far as food-relations are concerned. These are:

(*a*) *Producers:* These are the green plants which produce their own food, by trapping the energy of sunlight and transforming it with the aid of carbon dioxide and water into the form of food substances from which animals obtain their food. Thus green plants in a community serve this basic function.

(*b*) *Consumers:* These consist of some animals. They cannot manufacture their own food and so depend on continued supplies of ready-made food substances usually from plant sources for their energy and growth. There are at least two levels of consumers in an ecosystem:

(i) *Primary consumers:* These consist principally of animals (known as *herbivores* or *vegetarians*) which feed directly on plant materials. Examples are sheep, goats, squirrels, bees, etc. Man may be regarded as a herbivore when he eats spinach or cassava.

(ii) *Secondary consumers:* These are animals which do not feed directly on plant materials but rather on other animals (known as *carnivores*). Examples are dogs, cats, lions, leopards, etc. Man

may be regarded as a carnivore when he eats meat or fish. A secondary consumer may itself be eaten by yet another animal (a tertiary consumer).

(*c*) *Decomposers:* These are not often conspicuous in a community but fulfil a vital role. They are chiefly the soil micro-organisms, such as bacteria and fungi as well as earthworms, beetles and mites. Their function in the community is to decompose the organic compounds in the bodies of dead producers and consumers. This function of the decomposers makes available the mineral materials in the plants and animals so that they can be used again for the growth of new plants and animals. Thus if a particular community has no decomposers it cannot maintain itself, and indeed no community is known which has no decomposers. A community can exist without producers and in some cases without consumers but never without decomposers. The soil can be regarded as a community without producers. It consists of consumers and decomposers, and the food of the consumers may consist of leaf litter which can come from outside the soil under study which may not support any plants. The consumers consist of *detritus* feeders which reduce the leaf litter into small fragments.

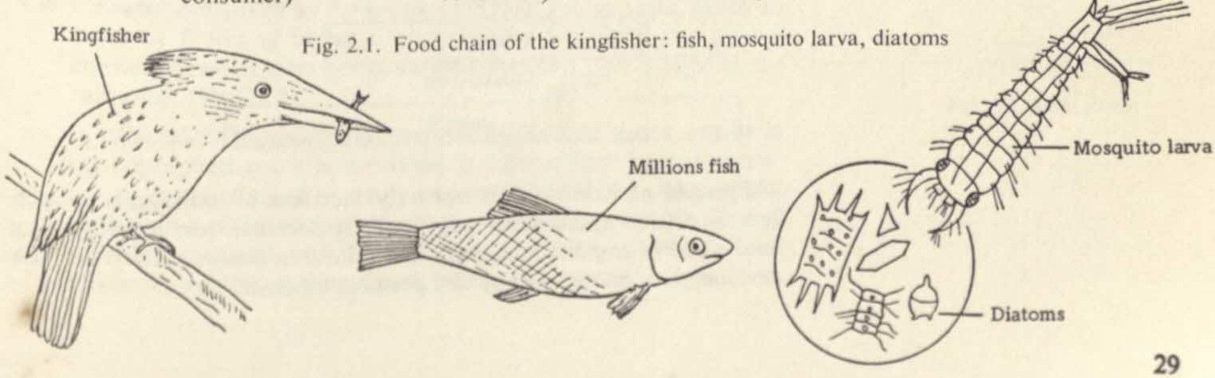
Food Chains (and Food Webs). From the above account of the different levels of performance of different organisms in an ecosystem it is conceivable that any particular organism in an ecosystem is, as far as its food relations are concerned, at a definite stage in a chain of events in relation to other organisms in the community. In other words the feeding status of every organism cannot be taken in isolation but in relation to other organisms which have played their part in making the food available to the particular organism, and to those whose feeding will be made possible later on. Thus the lives of various organisms are linked and can be traced back to plants. The sequence of events which show an ultimate dependence of animals on plants is known as the *food chain*.

For example diatoms being microscopic green plants (producers) are eaten by mosquito larvae (primary consumers); the larvae in turn are eaten by fishes such as guppies and millions fish (secondary consumers); finally the fishes are eaten by the kingfisher bird (Fig. 2.1).

The relationship may be set out in the form of a food chain as follows:

Diatoms ——→	Mosquito larvae ——→	Millions fish ——→	Kingfisher
(producer)	(primary consumer)	(secondary consumer)	(Tertiary consumer)

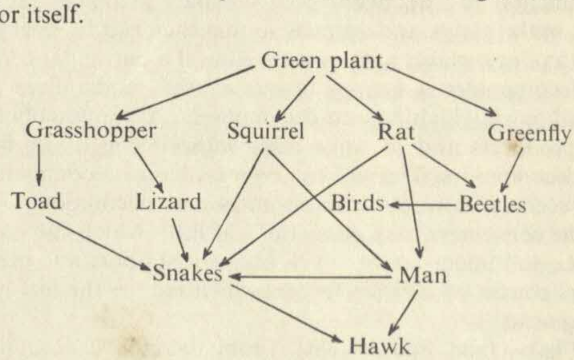
Fig. 2.1. Food chain of the kingfisher: fish, mosquito larva, diatoms



An example of a food chain typical of land conditions is as follows:

Leaves ⟶ Grasshoppers ⟶ Toads ⟶ Snakes ⟶ Hawks ⟶ Man.

Here clearly the chain is much longer. But there are much shorter ones at any stage of the chain. In other words the chain is never a single line as presented here but rather a tangle of various chains of different lengths forming a web. This is what is referred to as a *food web*. Let us look at the example illustrated in the diagram below which speaks for itself.



Pyramid of Numbers. If you study a particular food chain you will find that as you proceed from the producers (plants) the number of individual consumers decreases progressively while their size increases. This progressive decrease in numbers along the food chain in a community is called the *pyramid of numbers*.

In an intensive study of a habitat in Cape Coast (Ghana) the numbers of individuals found were approximately as follows:

Plants	..	900
Grasshoppers	..	300
Toads	..	100
Snakes	..	12
Hawks	..	2

If these figures are presented in the form of a *histogram* the result is that of a pyramid as shown in Fig. 2.2.

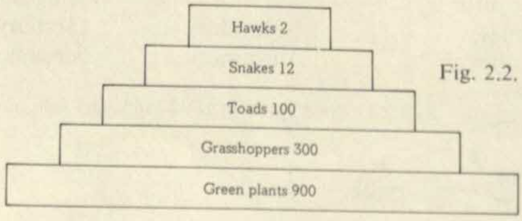


Fig. 2.2. Pyramid of numbers

Pyramid of Energy. It is not only numbers of individuals at each level in a food chain which progressively decrease from the beginning to the end of the chain. Energy also follows a similar pattern because no change of energy can be 100 per cent efficient.

To begin with the leaves of green plants are able to use only about 3 per cent of the light energy that reaches them from the sun while the rest escapes as heat. The energy absorbed is converted by photosynthesis into the potential energy of a food substance. Again when the primary consumer (herbivore or vegetarian) eats a plant material only a fraction of the energy stored in the plant is used to form the protoplasm of the animal while the greater part of it is lost as heat. The process is repeated thereafter with higher levels of consumers. The fraction of the food energy consumed by one organism which is converted into new protoplasm to provide the food energy for the next organism in the food chain is known as *the efficiency of energy transfer.*

Factors of the Habitat

Before we study particular types of ecosystems it is essential that we consider some of the factors of the environment which commonly affect any type of ecosystem be it terrestrial, freshwater, marine or arboreal. These factors may be considered under three main headings:

(*a*) *Climatic factors:* These include general climatic factors such as rainfall (and water), humidity of the atmosphere, temperature, wind and light.

(*b*) *Physiographic factors:* These are factors concerning the structure of the earth's surface at the habitat under study in relation to the rest of the surrounding area. It includes such features as rivers, mountains, hills, valleys and soil type.

(*c*) *Biotic factors:* These are the effects of living things, including man, in the ecosystem.

These three types of factors will be discussed a little further below.

(*a*) *Climatic Factors*

(i) *Rainfall and Water:* Since the high temperatures of the tropical weather result in rapid loss of water, the amount of rainfall is an important factor in the nature and distribution of vegetation. Thus, for example, tropical forests are found where there is not less than 125 cm (50 inches) of rain a year on the average, while savanna vegetation is established where rainfall is less than 125 cm (50 inches) a year. Even in the freshwater ecosystem rainfall is required to maintain the vegetation. Thus during the dry season standing waters evaporate rapidly and some of the plants perish while the remaining ones slow down in their growth as well as their rate of multiplication.

Some plants such as *Pancratium* respond rather significantly to rains by flowering in large quantities by the third day after a shower of rain or after being watered. Rainfall is measured by the *rain gauge* (Fig. 2.3).

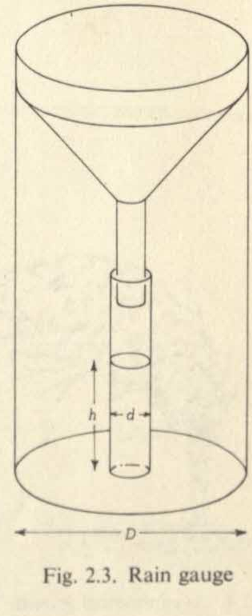


Fig. 2.3. Rain gauge

(ii) *Humidity:* Humidity refers to the amount of water vapour in the atmosphere but it is measured as a percentage humidity relative to saturated air at the temperature of the habitat. The amount present in a given ecosystem affects the height at which the bud is held on the plant, and the manner in which it is protected. Thus in the humid tropics trees have buds which are held high above

the ground and are thus exposed to the wind. In herbaceous plants however, the buds may lie just above the soil where the humidity is high. At the other extreme, as in bulbs and rhizomes the buds are buried beneath the soil where they do not experience the very low humidity of the dry period of the year.

Humidity is much lower during the day and much higher at night when it reaches saturation point and water condenses as dew on the leaves of plants in the early mornings.

In tropical forests the relative humidity is normally about 80 per cent but during the dry season it falls to 60 per cent. Different relative humidities exist at different heights in a forest, being much higher nearer the ground in the canopy. In many tropical savannas, the relative humidity can fall to as low as 5 per cent in the dry season.

(iii) *Temperature:* Even though temperatures in the tropics do not often drop to freezing point, they may vary quite significantly according to the season and the location of the habitat. Thus temperature varies with height and depth. A fall in temperature of about 1° C. takes place with every elevation of 200 m. For this reason the rather low temperatures found on say the Cameroon Mountains in West Africa (about 4 500 m high) support typical temperate plants like *Ranyuculus* and *Veronica.*

In the same way it is found that at a depth of 1,500 m in the Gulf of Guinea temperatures fall to as low as 5° C and at that depth a number of algae which are normally found in temperate waters are found in these tropical waters. Various kinds of thermometers are used for measuring temperature in the field.

(iv) *Wind:* When we come to consider the effects of the wind we find a number of effects. One of these is often noticeable on mountain tops and on sea coasts. On mountains strong wind succeeds in tearing away dead branches of trees and the vegetation may form rather low-lying mats. Where the prevailing wind with its adverse effects is predominantly from one direction, as is the case with the wind from the sea, the side of the plant which is directly in the way of the wind loses much water and thus gets so dry that new growth of branches is often made difficult. Of course the salt in the sea-spray helps the action of the wind in this case. Growth is much easier on the side of the tree that is away from the adverse direction of the wind. Thus many trees near the sea show one-sided growth which results in peculiar shapes. (Fig. 2.4.)

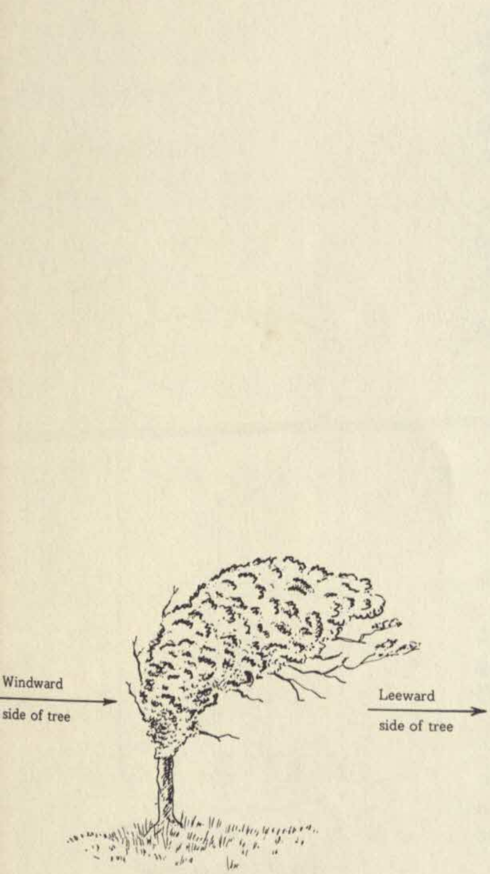


Fig. 2.4. Asymmetrical growth of a tree by the sea

Large trees may also be uprooted by the strong winds which sometimes precede rainfall.

In the case of water winds cause increase in wave action which may promote the mixing up of the upper warmer waters with the lower cooler ones. The direction and intensity of wind is measured by wind-gauges.

(v) *Light:* Light plays an important part in the distribution and orientation of plants. It also affects the flowering periods of some plants. Different plants have different light requirements; thus

some plants are light-demanding and are referred to as *sun plants* while others are shade-tolerant and are referred to as *shade plants*. In the tropical climate few of the plants are shade plants; among them are *Geophila* and *Costus* which are found in canopies of the forests. In freshwater too certain water-plants like *Ceratophyllum* and *Chara* are found only in dark depths of the water.

The demand for light by the individual leaves of a single plant results in what is often referred to as leaf-mosaic, whereby the leaves are so oriented that each of them gets some amount of light.

The amount of light which reaches the ground at the same latitude at particular times of the year determines the time of flowering of some plants. This was once thought to happen only in temperate plants because of the greater differences in the length of day throughout the year. Recent work, however, shows that this is also found in tropical plants and that even a difference of fifteen minutes of daylength can determine the flowering of some plants such as late *Okra* (*corchorus*) at Ibadan (Nigeria). Light is measured by the *photometer* or *photographic light meter*.

(*b*) *Physiographic Factors*

There are two aspects of this factor. These are:

(i) the aspect of the land surface (topography) which includes altitude, slope of land, drainage, mobility of the soil due to action of wind or tide, erosion and silting, and

(ii) soil factors, such as texture and physical, chemical, water and organic contents. Much of (ii) will be treated fully in Chapter 32.

We have already discussed the effect of high altitude on the type of plants that grow there. In some savanna areas a stretch of low-lying land may have forest vegetation because of the retention of water there for longer periods. The mobility of sand from the sea-shores cause the plants there to adapt against being dislodged. Also silting and wave action play an important part in the establishment of mangrove swamps. The nature of the land around a lake can influence the mineral and living organisms in it.

In the tropics *laterite*, which is soil containing iron salts, is a nuisance to plants growing in the shallow silt of soil which often covers it. The structure of the soil thus prevents leaching, since it does not allow the washing down of the mineral salts from the upper to the lower layers by the rain.

Soil erosion is rather serious in the tropics because of the force with which rain pours down. It is more pronounced in savanna areas where the land is virtually bare of vegetation during the dry season so that the raindrops fall directly on to the soil.

(*c*) *Biotic Factors*

(i) *Green Plants:* Green plants play an indispensable role in the ecosystem by reason of the food they manufacture through photo-synthesis. The food so manufactured serves not only themselves but also all non-green plants as well as animals and man. Some plants, especially trees, modify the environmental factors of plants

below them. Plants may also compete for light, water, space and some minerals especially where different species exist in close proximity, as typical of tropical vegetation.

It is noted for example that the grass *Andropogon* often replaces *Imperata* because of the greater height and the shade it casts on *Imperata* as well as its aggressiveness in spreading.

Epiphytes, being green plants that grow while standing on larger green plants, compete with the branches of the host plant for light.

(ii) *Non-green plants:* Non-green plants, which include bacteria and fungi as well as other more advanced plants, play various roles in the ecosystem, the chief among them being those of (*a*) decomposers, (*b*) symbionts and (*c*) parasites. These are described in detail later.

(iii) *Animals* (*other than Man*)

Animals use plants basically as food but apart from this there are other effects of animals on plants which are rather varied. Among these are:

1. Direct destruction of vegetation as in the case of large animals like elephants and baboons.

2. Destruction of vegetation through feeding as in the case of swarms of migratory locust.

3. Change of vegetation through overgrazing by domesticated animals like cattle.

4. Transmission of diseases as in the case of the mealy-bug insect which sucks the juice of the cocoa plant and introduces the virus of the swollen-shoot disease which it had got from a diseased plant.

5. Pollination of plants: birds pollinate red-coloured flowers like *Bombax*, while bats pollinate flowers of the silk-cotton and the *Baobab* tree.

6. Dispersal of seeds and fruits: various animals are responsible for the dispersal of seeds and fruits thus helping to widen the area covered by the plants concerned and to bring them into new habitats.

7. Enrichment of the soil: animals play a part in the movement of nutrients in the soil thereby making more nutrients available to plants. Termites are able to do so by virtue of their action in the soil and on timber. Crabs bore many holes in the mangrove swamp and thus make oxygen available to the roots of mangrove plants.

Special Relationship amongst Plants and Animals

Some plants and animals exhibit certain special relationships in a community largely through their mode of nutrition and these are among the biotic effects in the community. Among these special relationships are: *symbiosis*, *parasitism*, *semi-parasitism*, *saprophytism* (decomposition) and *epiphytism*.

Symbiosis. Symbiosis is the term used to describe the situation when organisms live together and benefit mutually by their association. It is like a 'marriage' between the two organisms. Either two animals, or an animal and a plant, or two plants may live in a symbiotic relationship.

An example of two animals living together is provided by the hermit crab and the sea anemone (Fig. 2.5). The hermit crab is a creature that lives with its body coiled in the empty shell of a whelk or other mollusc.

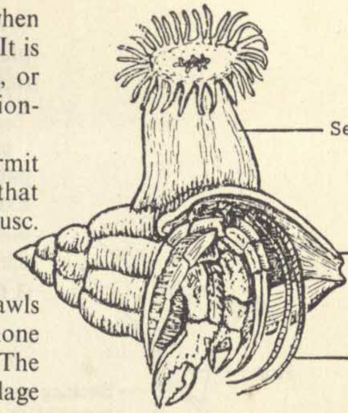


Fig. 2.5. Symbiosis of the hermit crab and the sea anemone

Its head and legs protrude from the mouth of the shell when it crawls about dragging the shell after it. The hermit crab allows a sea anemone to grow on the shell and both animals benefit by the association. The sea anemone helps the hermit crab not only by providing camouflage which protects it from its enemies but also by providing defence through its power of stinging. In return the hermit crab aids the anemone by carrying the latter to good feeding areas and also by providing it with food remains on which the anemone feeds.

An example of symbiosis between a plant and an animal is offered by the green *Hydra* many of whose cells contain minute green plants. The plants use carbon dioxide and nitrogenous waste produced by the *Hydra* while the animal benefits by the release of oxygen and perhaps gains some carbohydrates.

An example of symbiosis between two plants is afforded by the presence of root nodules (Fig. 2.6) on leguminous plants such as peas and beans. These nodules are swellings of the root tissues of the plant and contain bacteria, which are regarded as plants, which feed on the carbohydrates in the root tissues. The plant also makes use of some of the nitrogenous matter which the bacteria are able to build up from the nitrogen in the air between the soil particles. The role of root nodules in the nitrogen cycle is discussed later in Chapter 32. It may be mentioned here that this type of symbiosis makes such plants valuable sources of nitrogen for the soil.

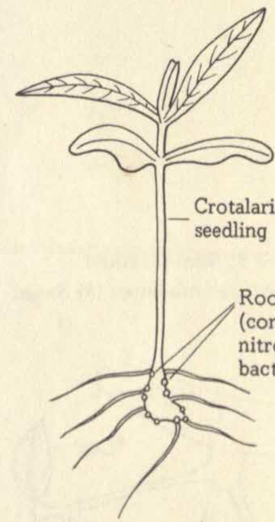


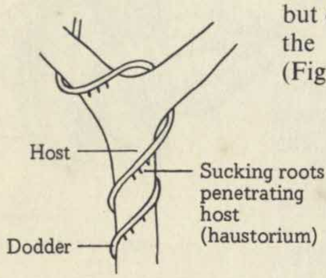
Fig. 2.6. Root nodules on a leguminous seedling plant (*Crotalaria*)

Parasitism. Parasitism is the name given to an association between two organisms from which only one benefits. The organism which benefits is known as a *parasite* and it causes harm or inconvenience to the other organism (known as the *host*) in the process of obtaining its food. In this respect parasitism differs from another type of association between organisms, known as *commensalism*, where no harm or inconvenience is caused to one partner through the benefit derived by the other. An example of commensalism is provided by the free-living microscopic animal *Opalina*. This animal lives in the intestines of toads from which it derives its food without apparently causing any inconvenience to the toad.

There are many examples of parasites which cause disease in animals. For example the malarial parasite (called *Plasmodium*), which is carried by the mosquito, lives part of its life in, and derives its food from the red blood-corpuscles of man where it produces poisons which cause malaria. Other examples of parasites are the tape-worm, found in pigs and man, and the liver-fluke found in the liver of sheep.

An example of a parasitic relationship between an animal and a plant is afforded by the ring-worm fungus. This subsists on the living tissues of the human scalp and causes the disease known as ring-worm.

A plant can also parasitize another plant. An instance is the yellow parasite dodder *Cuscuta* which grows on ordinary green garden shrubs. Except for a short period after germination this parasite has no roots but develops suckers, or *haustoria*, which penetrate into the tissues of the host and through which the dodder obtains food and water (Fig. 2.7).



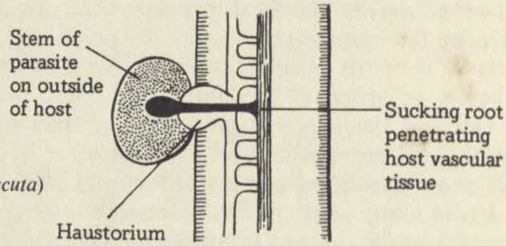
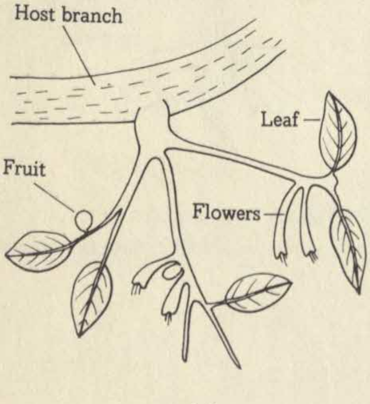
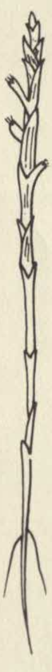


Fig. 2.7. Dodder parasite (*Cuscuta*)





(a) (b)

Fig. 2.8. Semi-parasites: (*a*) African mistletoe; (*b*) *Striga*

There are a few cases where parasitism is not total and the plants are known as semi-parasites. The semi-parasitic plant obtains only part of its food from the host plant because, unlike the total parasites, it contains chlorophyll which enables it to make up its own food supply by means of photosynthesis. Well-known examples are the 'African mistletoe' called *Loranthus* and *Striga* (Fig. 2.8). The mistletoe, with its elongated clusters of bright red flowers looking like red candlesticks, is found on many tropical trees. It has no roots but is able to absorb water and mineral salts from the sap of the tree on which it grows and its rather leathery green leaves make more food by photosynthesis. *Striga* is often found attached to the roots of grasses from which it absorbs part of its food. The plant has a greenish, wiry stem with a few small leaves which carry on photosynthesis.

Saprophytism. We may just mention the mode of feeding of the fungi—a group of plants which have no chlorophyll. These obtain their food by absorbing ready-made food substances from the material on which they grow. Such material may consist of dead tissues. Plants which feed on dead tissue are called *saprophytes* and examples are discussed in Chapter 21. They are responsible for the rapid decay of broken trees in our forests. Saprophytes digest their food by means of enzymes.

Finally we have some cases where one plant may be found standing on another but where there is in fact no union between the two plants. These are called *epiphytes*. They merely grow in the soil and other debris collected in the trunk of the tree. This is more fully discussed in Chapter 32.

SUGGESTED PRACTICAL WORK

1. *Succession.* (*a*) It is quite impossible in most cases to study succession in the real sense even over the period of your studies at the school. However in tropical climates certain situations can be studied in place of this. In the area of your school look for a water-pond which completely dries up in the dry season. Start observing it at the end of the rainy period when the pond is full of water. Make a list of the plants and animals found

(i) at the middle of the surface of the water and

(ii) at the edges of the pond.

Repeat the observation every month till the pond dries up completely and leaves a bare soil in its place. Note particularly the plants and animals that disappear and those that appear over the period and how they are adapted to the changing conditions.

This will give an idea of the succession that is expected from water to land conditions.

(*b*) You can also study succession on a newly felled log by observing the plants and animals that develop at say weekly intervals.

2. *Food chains.* Spend ten minutes each day for a whole week studying the feeding habits of an easily observed animal such as a lizard, a chameleon, a bird or a praying mantis. Record answers to the following questions:

(*a*) Did any other animal attempt to attack or eat the animal being studied?

(*b*) What food did the animal eat?

(*c*) If the prey was a different animal, try to discover its feeding habits.

Choose two food items of animal origin—for example, liver, snail or fish—and construct a food chain for each item. It is also possible to study food chains by constructing an aquarium (see No. 5 below).

3. *Root nodules.* Dig up a leguminous plant—for example, a groundnut plant, a bean plant or a pea plant—and wash the roots carefully.

Notice that there are small nodules distributed sparsely all over the roots. Attempt germination experiments with seeds of the groundnut plant as follows:

(*a*) Sow one set of seeds in a box of ordinary soil.

(*b*) Sow another set of seeds in a box of sterilized soil or in sand.

Compare the external appearance of the roots of each batch of seedlings. Offer an explanation for the results of the germination experiments.

4. *Parasites.* The dodder is a common plant parasite introduced into many tropical countries. It is often found with its tangled mass of yellowish stems on *croton* and other decorative plants. Look out for dodder in the flower gardens in your school or in neighbouring houses and make a note of the plants on which it occurs.

'African mistletoe' (*Loranthus*) is commonly found growing on the branches of other plants. Go out and collect some *Loranthus* and try to answer the following questions:

(*a*) Does *Loranthus* grow on any kind of tree or is it restricted to a few species of tree only? Name the trees.

(*b*) Is *Loranthus* totally parasitic or is it semi-parasitic?

(*c*) How is *Loranthus* attached to its host plant?

(*d*) Does *Loranthus* seem to be damaging the host plant?

(*e*) What kinds of flowers and fruits does *Loranthus* produce?

(*f*) How are the seeds of *Loranthus* dispersed?

5. *How to construct an aquarium.* Get a large glass vessel and clean it to remove traces of soap and dirt. Place at the bottom of it washed sand and some stones on which small plants can grow. On the sand pour water obtained from the pond from which organisms are collected for the aquarium. Place in it suitable plants: these may include submerged ones like

Ceratophyllum, partly submerged ones like the white water-lilies (*Nymphaea*) and some floating ones like the water-lettuce (*Pistia*) and water-ferns (*Azolla* and *Salvinia*). The floating plants provide a light screen as well as hiding places for the animals in the water. Animals are added later: these include small fish like millions fish, and water-snails to feed on the green algae which soon form a film on the glass; mosquito larvae may also be added to provide food for the millions fish. It is essential to cover the aquarium with glass so that the animals cannot get out.

Aeration is afforded by the production of oxygen by the plants as a result of photosynthesis, while the movement of the fish stirs up the water. It is important that the aquarium should not be placed in direct sunlight since this will heat the water and eventually kill some or all of the animals. The water should be replenished from time to time as evaporation reduces its original quantity.

A balance of life is soon established in the aquarium. When animals die their remains provide material for increased growth of plants although when too much debris accumulates at the bottom it should be carefully removed without disturbing the organisms. Siphon it off with the aid of rubber tubing. Small amounts of bread may be added daily for the millions fish, and minced meat for the tadpoles. Remove any uneaten bread or meat to prevent decay and contamination.

6. *Climatic factors*. Your school may have a permanent station for recording rainfall, humidity, temperature, light intensity and air movements. If so, learn how these records are taken and keep the records. Records kept throughout the year would enable you to make comparisons at different seasons with a nearby community which you may study for different ecological principles.

7. *Man*. Man is the most powerful destroyer of the ecosystem. His activities on the ecosystem include the following:

(*a*) Felling of trees—for use as timber, or as fuel either directly as firewood or converted into charcoal.

(*b*) Farming—which exposes the land to erosion and thus makes it difficult for the return of the original vegetation. The practice of shifting cultivation is even more wasteful of land.

(*c*) Fire—the effect of fire is more noticeable in the savanna where apart from the *geophytes* and grasses only the thick-barked, fire-resistant, woody species eventually survive. When this happens annually the vegetation does not grow beyond a certain height. In West Africa the savanna seems to have advanced into the rain forest because the annual fires kill the seedlings of the forest trees.

(*d*) Other equally important activities of man disturbing or destroying the ecosystem include urbanization, drainage of swamps and irrigation of land.

CHAPTER THREE

Ecology (continued): Types of Communities

As STATED earlier the two basic types of habitats are the aquatic (or water) and the terrestrial (or land) types. There are however different forms of each of these. The aquatic habitat, for example may be either (a) *freshwater* (that is a pond, a lake, a lagoon or a river or stream) or (ii) *estuarine* (that is where fresh and salty waters mix up), or (iii) *marine* (that is in, or close to the sea).

The terrestrial habitat may also be either (i) *ground-level*, (that is on the surface of the earth) or (ii) *arboreal* (that is on or in trees) or (iii) *underground* (that is below the surface of the earth). We shall now proceed to examine the peculiarities of the two basic types of habitat and to describe examples of freshwater, the estuarine, ground-level and the arboreal types since they are more easily studied than the marine—underground habitats are rather difficult to study at this stage.

Special Factors and Adaptations of the Aquatic Habitat

The aquatic habitat presents special problems to plant and animal life, and as we would expect, the organisms seem to have evolved, over the years, a number of features that enable them to cope with the problems of the environment. Among these are the following:

(*a*) *Reduced Gaseous Exchange:* In water there is a higher concentration of dissolved carbon dioxide but a lower concentration of oxygen than in the air.

Water-plants meet this problem by having plenty of air-spaces in their tissues in which gases are stored (Fig. 3.1). Oxygen accumulates in these spaces during the day and is replaced at night by excess carbon dioxide which accumulates when photosynthesis ceases and respiration continues.

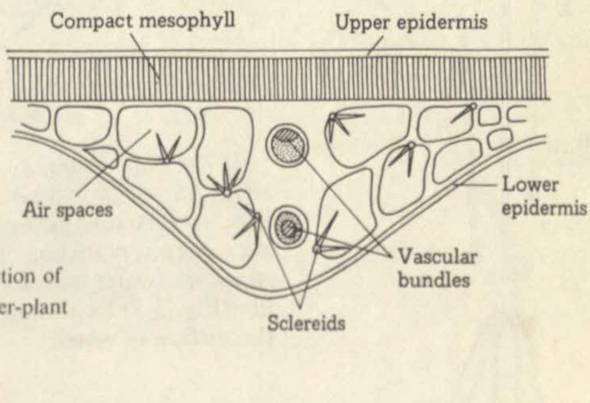


Fig. 3.1. Cross-section of leaf of typical water-plant

(*b*) *Reduced Light:* Particularly in submerged water-plants the amount of light which is received in water is rather small, since much of it is absorbed by the top layers of the water.

To meet this situation the leaves of water-plants are often thin and flat, and chloroplasts are present even in the ordinary epidermal cells (which in land plants have no chloroplasts) in both the leaves and the stems. In this way the water-plants are able to make fuller use of the little light that reaches them for photosynthesis.

(*c*) *Buoyancy:* All water-plants are, to some extent, supported by the water. They therefore would appear not to require such supporting tissues as do land plants.

It is found that water-plants tend to have rather reduced vascular tissue.

(*d*) *Reduced Transpiration:* The environment of the water-plant is very humid, so that unlike land plants transpiration is much checked.

The plants usually have poorly developed stomata which are often present only on the upper surface. The epidermis of the leaves and the stem also has no cuticle which is commonly found in the case of land plants. There are no root-hairs, and the amount of water-conducting tissue (xylem) is greatly reduced. Thus both transpiration and water absorption are reduced in water-plants.

The Freshwater Pond

A freshwater pond is a common example of a freshwater habitat. It can easily be studied where it is available. Where it is not available, an aquarium can be studied (see end of Chapter 2). In a pond there are four positions in which the factors of the aquatic habitat, just described above, are present in such different combinations, that the organisms there are differently adapted. These are (i) the top central zone, (ii) the top edge zone, (iii) the deeper (central) zone and (iv) the bottom zone. (See Fig. 3.2.)

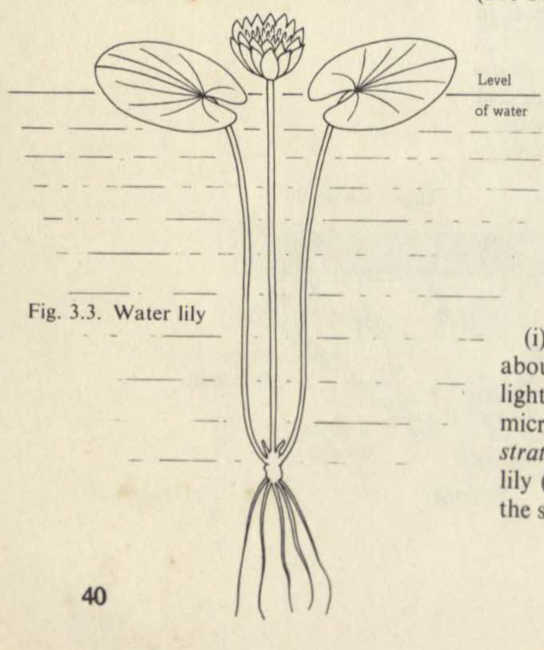


Fig. 3.3. Water lily

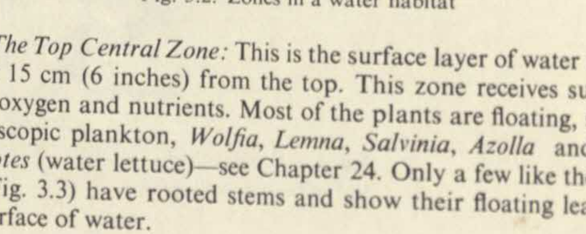


Fig. 3.2. Zones in a water habitat

(i) *The Top Central Zone:* This is the surface layer of water usually about 15 cm (6 inches) from the top. This zone receives sufficient light, oxygen and nutrients. Most of the plants are floating, such as microscopic plankton, *Wolfia*, *Lemna*, *Salvinia*, *Azolla* and *Pistia stratiotes* (water lettuce)—see Chapter 24. Only a few like the water lily (Fig. 3.3) have rooted stems and show their floating leaves on the surface of water.

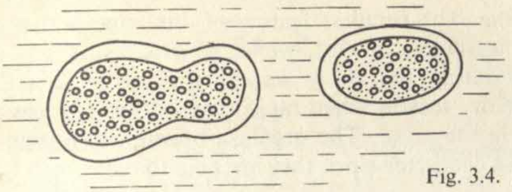


Fig. 3.4. *Wolfia*

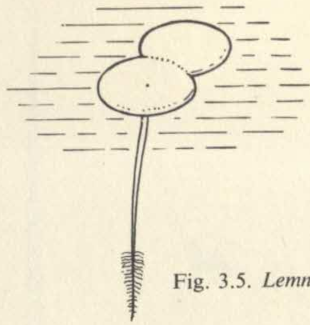


Fig. 3.5. *Lemna*

Most of these plants are small in size, and this seems to be an adaptation to buoyancy. *Wolfia* (Fig. 3.4) reputed to be the smallest flowering plant consists of a tiny round leaf and a tiny root hanging from it. *Lemna* (Duckweed) (Fig. 3.5) is only about twice the size of *Wolfia*. *Salvinia* (Fig. 3.6) and *Azolla* (Fig. 3.7) are water ferns with reduced leaves. One of the largest of the floating plants, the water lettuce is also well adapted. It has hairs on the leaves which prevent wetness and reduce the density of the leaves, making the leaves cushion-like. The leaves and even the roots contain large air-spaces

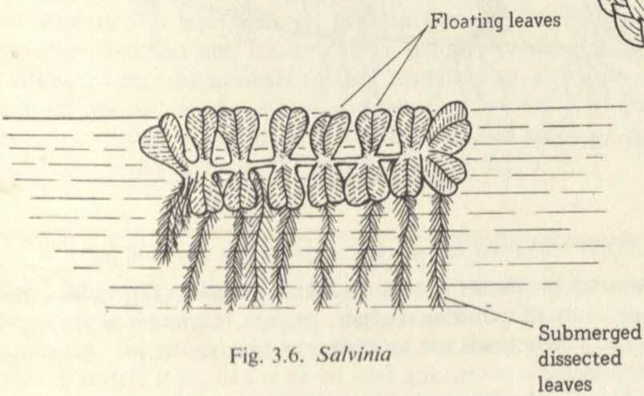


Fig. 3.6. *Salvinia*

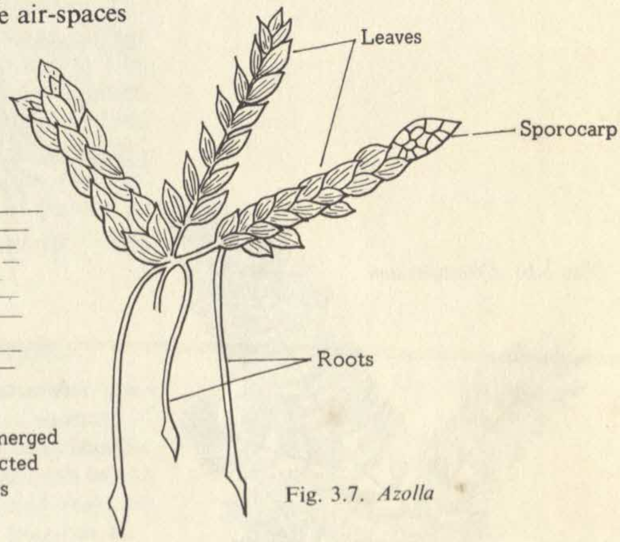


Fig. 3.7. *Azolla*

which help the plant to float. The animals in this zone are also free-floating and consist of microscopic plankton, water bugs, pond skater (*Gerris*), tadpoles, the diving beetles (*Dytiscus*) and the water scorpion (*Nepa*). This zone is also visited occasionally by aquatic birds such as the black tern.

The animals are also typified by reduced weight which assists in floating. For example the pond skater has a slender body, four of its legs are rather elongated and carry the weight of the body when the insect skates on the water surface. (See Fig. 3.8.) A water bird like the black tern supports itself in the water by means of its very long toes. Those insects in this zone which sometimes stay just below the surface of the water use the air bubbles which they entrap in the fine hairs on their body. In the case of the larvae and pupae of mosquitoes air supply is obtained through their siphons which are connected from below to the surface of the water (see Chapter 8).

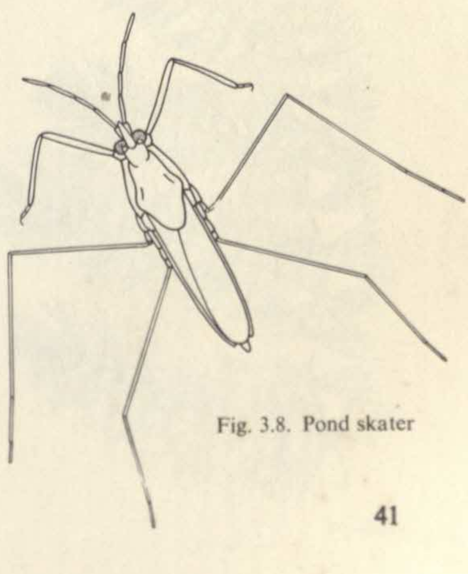


Fig. 3.8. Pond skater

(ii) *Top Edge Zone:* The peculiar feature of this zone is that the amount of water fluctuates, in that, while the organisms here are covered by water during the rainy season, they may be rather exposed during the dry season when rapid evaporation reduces the level of the water in the pond. The organisms therefore appear to have an amphibious character since they are able to cope with both situations.

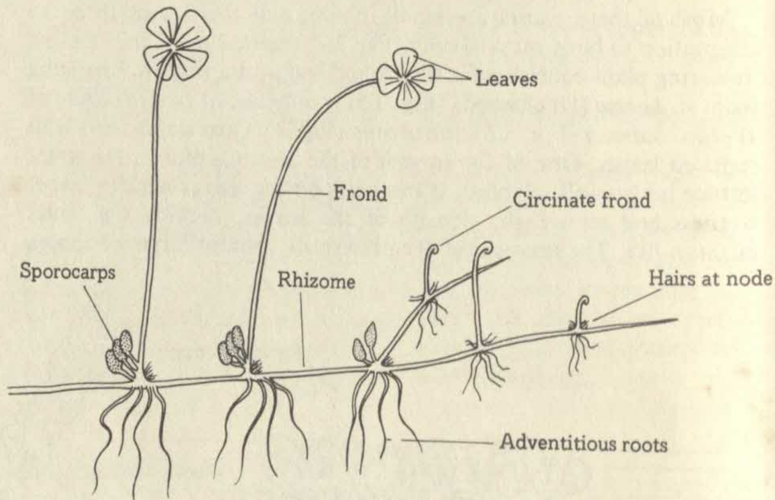
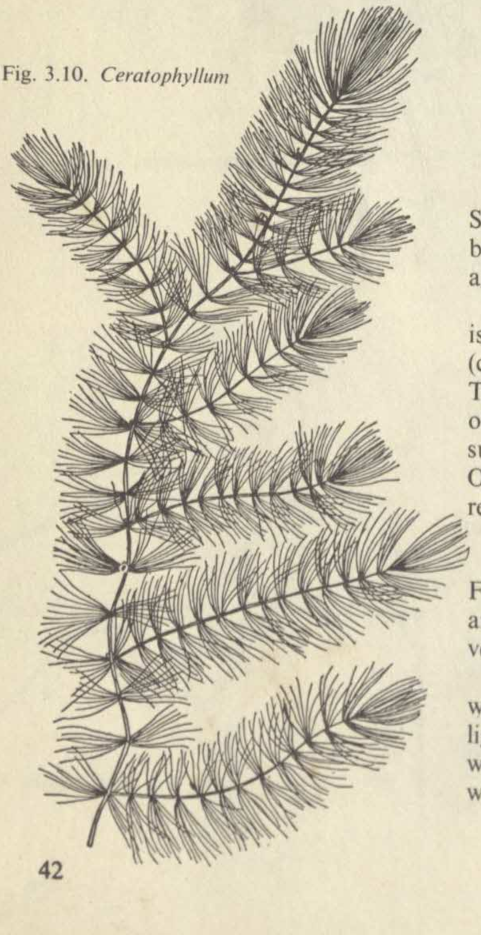


Fig. 3.9. *Marsilea*

Fig. 3.10. *Ceratophyllum*



Among the plants in this area are *Marsilea* (Fig. 3.9), *Jusseae*, Swamp arum (*Sagittaria*), sedges, grasses, *Commelina* species and bamboos. The animals are amphibious like tree frogs, water snakes and dragon flies.

(iii) *The Deeper* (*Central*) *Zone:* In this zone the amount of light is reduced because the rays of light first pass through the upper (central) zone where much of it is absorbed by the organisms there. The light which passes through the water spaces which have no organisms gets into this deeper (central) zone. This region is not subject to temperature fluctuations and water movement is minimal. Oxygen content is lower here while carbon dioxide content is relatively higher.

The plants are submerged types like *Ceratophyllum* (hornwort) Fig. 3.10., *Ceretopteris* and the bladderwort (*Utricularia*). The animals consist of insect larvae, fishes, freshwater snails (on the vegetation) and hydroids.

The adaptation of the plants here is exemplified by *Ceratophyllum* with its tiny dissected leaves for making good use of the rather poor light. The fishes have streamlined shape which is suited to movement with minimum friction in the water. Breathing is by means of gills which are suitable in water (see Chapter 11).

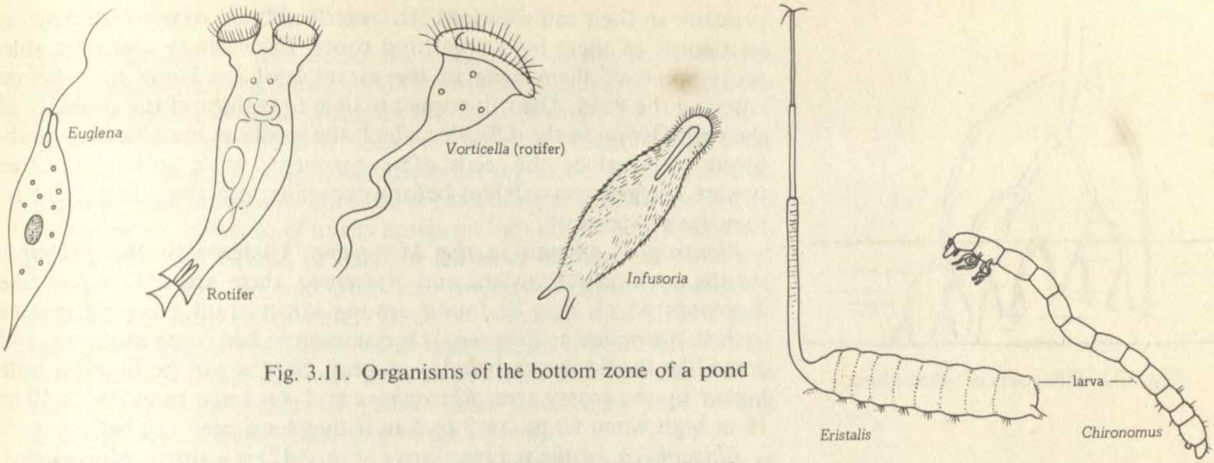


Fig. 3.11. Organisms of the bottom zone of a pond

(iv) *The Bottom Zone:* Here light intensity is lowest and is often dark. Nutrients accumulate owing to the absence of currents. Carbon dioxide is much higher here, and consequently oxygen is very low.

Plants are rare here except for the roots of the water-plants showing in the layers above. Animals consist of worms, leeches, molluscs, rotifers and larvae. Since there is practically no photosynthesis here, the animals in this zone feed on detritus. They are adapted to conditions of low oxygen, in some cases by having an oxygen-carrying pigment as in the *Chironomus* larva or by having long siphons as in *Eristalis* larvae. (See Fig. 3.11.)

Special Factors and Adaptations to the Estuarine Habitat

The Mangrove Swamp. This is often found in the tropics near positions where a river and the sea meet, where the floor is made up of particles of soil which are deposited at the mouth of the river. The habitat is rather difficult for plant and animal survival because of the following factors which illustrate the special features of the estuarine habitat.

(*a*) *Fluctuating Salt Content:* The mangrove swamp is essentially tidal, receiving water of lower salinity from the river and of higher salinity from the sea at different times each day. The plants and animals in the mangrove will thus have to be adapted to withstand such changes in salinity.

(*b*) *Aeration:* The soil in the mangrove swamp is saturated and hence almost completely lacks the oxygen required by the plants for respiration. Only a limited number of plants can live under these conditions.

(*c*) *Mobility of the Soil:* The soil level is not stable because the rivers often bring down alluvium to raise the level of the soil, and this is disturbed by future sea currents which wash away the soil, so that it is difficult for seedlings to establish themselves on the silt.

The few plants that are found in mangrove swamps are adapted in their physiology to withstand the fluctuations in salt content, since a number of them are halophytes, that is, are plants with high osmotic

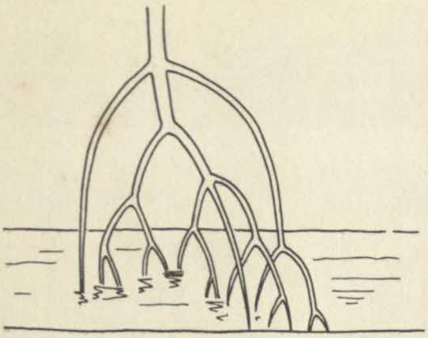


Fig. 3.12. Stilt-roots of *Rhizophora*

pressure in their cell solutions. In order to obtain oxygen for respiration some of them have breathing roots. Even where there are stilt-roots some of them hang in the air at least for some time before entering the mud. The stilt-roots are able to withstand the mobility of the soil. Owing to the difficulty which the seedlings may have in establishing themselves, the seeds often germinate while still on the tree (where oxygen is available) before dropping into the water (that is, they are viviparous).

Plants and Animals in the Mangrove: Underneath the principal shrubs such as *Rhizophora* and *Avicennia*, there are halophytes like *Sesuvium* which may be found among salt-tolerant creeping grasses such as *Paspalum* or *Remirea*. It is common to find some molluscs, and crabs like the fiddler-crab and buck-crab. Shrubs will be found a little higher up the grassy area. *Rhizophora* and *Avicennia* range from 10 to 15 m high when virgin, or 3 to 5 m if they have been cut before.

Rhizophora, or the red mangrove (Fig. 3.12) is a shrub whose lower part bears stilt-roots, which support it. At the end of each of the roots are numerous lateral roots which provide firm anchorage in the mud. The plant is viviparous, that is, the seeds germinate and develop (in the leathery fruit) while still attached to the plant (Fig. 3.13). A long radicle with two or three shoots is produced before the seedling falls into the water. The radicle is long enough to keep the seed above water. The seed then drifts to the bank where it becomes rooted in the mud.

Avicennia, or the white mangrove protrudes from the soil into the air over a wide area surrounding the mangrove. Although not viviparous, the embryo is in such an advanced condition that the seed germinates rapidly.

The fallen leaves of these shrubs provide organic debris. Animal visitors like the catfish, brought in by high tide from the sea, feed on this debris.

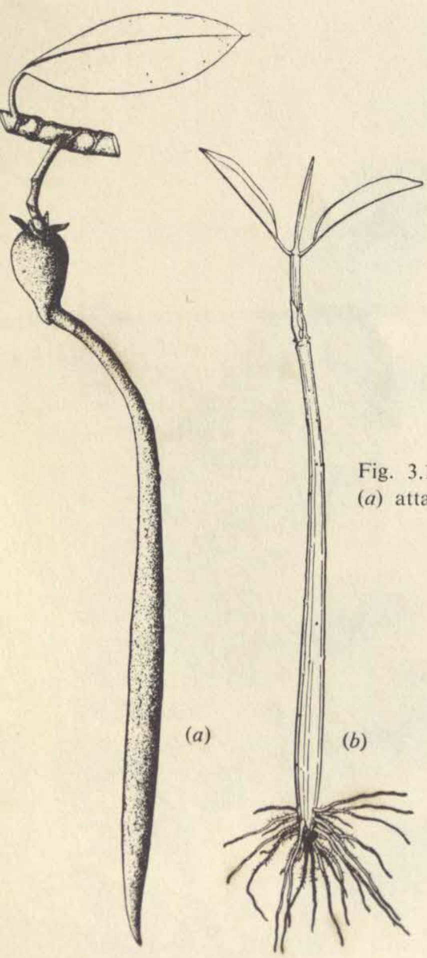
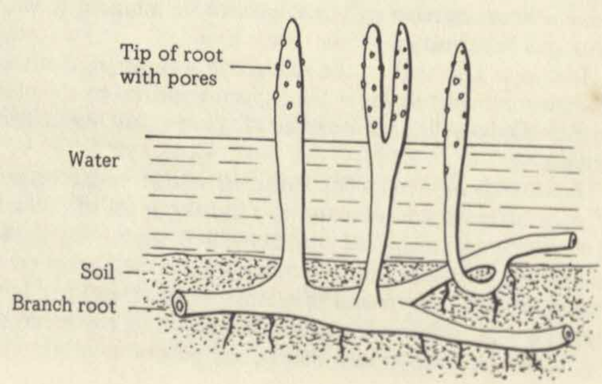


Fig. 3.13. Germination of fruit of *Rhizophora*:
(*a*) attached to parent plant; (*b*) independent seedling

Fig. 3.14. *Avicennia*



The Terrestrial Habitat

As can already be seen under the conditions of the sea-shore (or strand), land conditions are rather different from the aquatic conditions in many ways. Among the problems are the following:

(*a*) *Desiccation:* This is perhaps the greatest problem to organisms on land. Thus most of the adaptations are for economising on water. This includes the reduction in the permeability of the skin by means of wax or the presence of horny scales on the skin, or the production of a waterproof cuticle, or hairs or leaves or feathers on birds and hair in mammals. In land crabs and insects the chitinous covering helps to prevent loss of water. In some mammals and birds a portion of the kidney re-absorbs water and releases concentrated urine. It is also found that birds use their cloaca to re-absorb water and to release semi-solid pellets of urine. Land plants also have strong development of water-absorbing tissue (xylem).

(*b*) *Reproduction and Development:* The problem also exists of ensuring fertilization and development of the young and dry land. Unlike aquatic animals where gametes are shed into the sea so that fertilization takes place externally, in land organisms this is impossible. Here fertilization in animals becomes internal and structures exist to protect the embryo against desiccation. Examples include the development of earthworms in cocoons, insects in 'bags', birds and reptiles with strongly shelled eggs. Mammals are typified by the development of the uterus and the placenta which protect the fertilized ovum to an advanced stage before delivery (vivipary).

In plants we have already noticed vivipary in the mangrove plant *Rhizophora*.

(c) *Respiration:* On land the respiratory apparatus is adapted to its function with limited supply of water, hence the tracheal and lung systems in mammals as opposed to gills in water.

Prominent stomata on leaves of land plants and lenticels on stems and roots are also significant adaptation to conditions on land.

(*d*) *Supporting Tissues:* Land plants have to carry themselves and may be moved about by wind. Thus they have a great deal of supporting tissue (such as sclerenchyma and collenchyma). In the tropics owing to the increased desiccation due to the high temperature, most plants show tissues and features typical of plants in specially dry places (xerophytes).

Major Terrestrial Habitats in the Tropics

The major terrestrial habitats in the tropics are the forests, the savanna and the desert. These will be briefly described below:

Tropical Forests. Tropical forests in equatorial regions are perhaps the most remarkable of all vegetation types in the world. The original and undisturbed type of forest (the rain-forest) has conditions which do not seem to change throughout the year with rainfall occurring almost every day of the year, whereas the disturbed and other types do not receive the rains throughout the year but have a period of much reduced rainfall. While the trees of the first type of forest are evergreen

and do not lose an appreciable quantity of their leaves at any particular period of the year, the second type often contains a number of trees which lose much of their leaves during the period of reduced rainfall.

In spite of those broad differences the tropical forests have enough characteristics in common which can be considered here. Temperature is relatively high and uniform, with an annual mean around 25° C and 35° C. The rainfall is often rather high totalling between 200 and 400 cm annually. The upper canopy of the forest is exposed to bright sunshine, winds and low humidity while in the lower canopy there is relative darkness, little or no wind blows through and the atmosphere is very humid.

The animals which feed on the fruits of the forest trees are found mainly in the tree-canopy. They include monkeys, birds, squirrels, lizards and snakes.

Structure. The tropical forest is noted for consisting of a large number of different kinds of tall trees and other woody plants. The trees are no doubt the prominent component of the forests, and they are typically made up of more or less three levels in height (called *strata*) each of which may consist of different types of trees. Since there are trees at different stages of development, it is not always easy to notice these three levels in height. The forest trees are rather uniform in appearance, being straight and slender. The leaves of the trees are often dark-green with glossy surfaces. Many of the trunks of the trees are covered by leaves of climbers of all sorts. The flowers of the trees are very small, and the trunks often have buttress roots.

Below the two or three tree levels may be found a shrub layer consisting of tall woody plants, and a ground layer of herbs and seedlings of trees. Although the conditions are humid and warm herbs are not so common on the ground because enough light does not reach the ground.

Tropical forests are typified by the large collection of woody climbers (called *lianes*), epiphytes and stranglers. The latter are plants that begin life as epiphytes but later develop roots into the soil.

Seasonal Changes. In the tropical forests, loss of leaves, development of new leaves, flowering and fruiting seem to take place at almost any time of the year, only particular kinds of plants being involved at each time. This means that at any time that one visits the forest one would most likely find some kind of plants losing their leaves, others developing new leaves, others flowering and still others fruiting.

Factors of the Habitat (including influence of Man). The essential factors of the environment of the tropical forest as mentioned above are rainfall, light, humidity, animals and finally Man.

Rainfall is required at the high level of 200 to 400 cm per annum in order to maintain the tropical forest. The competition of the plants and their different requirements for light contribute to the presence of the different levels in height (strata) in the forest.

The seeds of many forest trees are dispersed by wind and animals. Where the seeds are dispersed by wind, they often do not fall far off from the mother tree and thus remain in the dense shade and damp conditions of the forest floor which are not suitable for germination

and survival of many seedlings. Hence most forest trees have rather poor seed germination.

Large animals like elephants uproot forest trees by pushing them with their bodies as they pass through the forest especially after heavy rains. Monkeys feed on the fruits of many trees, and in some cases they feed on rather immature fruits, thus reducing the chances of getting more of that particular kind of plant in the forest.

The activities of Man in the tropical forest have been remarkable—the exploitation of trees for timber and the destruction of forests for the establishment of farms for cash crops like cocoa, oil-palm and rubber. Most of the forest trees are easily damaged by the fires which farmers often use in preparing their farms. Finally in order to build roads, houses and to establish towns and cities, Man has done considerable damage to the tropical forests.

The Tropical Savanna. The savannas normally consist of large stretches of grass and grass-like vegetation interspersed with trees many of which are deciduous. Unlike the forests, the savanna trees are often widely spaced out and this means that light can reach the ground vegetation. It is only in very favourable places such as hollows and banks of water-courses that the trees grow closely together. The grasses grow in tufts and are usually taller than a man. The bush fires which are found each year in grasslands are found to be largely responsible for the creation of the savannas because the fires more readily destroy woody plants and palms (except for fire-resistant trees) but do not destroy the underground parts of grasses. The result is that the grasses are able to grow up again when the rains come on. Bushes with small and hard evergreen leaves or thorns are often found among the grasses.

The trees of the savanna are usually stunted and the barks are disfigured as a result of the annual fires that sweep past them. They range in height between 5 and 15 metres. The species found here are largely different from those found in the forests, and often include the palms. Among the fast growing grasses is the Elephant Grass (*Pennisetum*) which may grow to a height of about 5 m and become rather impenetrable. The trees commonly include members of the Pea family (*Leguminosae*) such as the acacias. In Africa another typical tree is the *Baobab* (*Adansonia*) which has a huge water-storing trunk, with a thick and corky bark. Some of the trees tend to have relatively low and compact crowns shaped like an umbrella.

The weather of the tropical savannas is hot, with a moderate range of temperature. The rainfall is also moderate, often about 110 cm per annum. The rain falls during one period of the year followed by a period of drought. The period of the rain in relation to the dry period results in some seasonal changes in vegetation in the savanna. These are (i) the cool and dry period of the year: during this period fresh leaves and flowers are formed on the trees and the grasses begin to grow, while perennial plants with underground organs, such as tubers, bulbs and rhizomes, like the ground orchids appear, (ii) the warm and rainy period when the trees develop a dense canopy and the grasses (among which is Elephant grass) grow to such a height that it is difficult for a man to see for any distance and when large areas may be

under water, (iii) the hot and dry period in which the trees shed their leaves, the grasses wither and bush fires become common.

Generally savannas lie between forests and deserts, so that those that are found near the forests are wetter than those found nearer to the deserts. This is because the rainfall decreases as one proceeds from the forest vegetation to the deserts. The savannas nearer the forests often have rainfall between 85 and 125 cm and the trees have relatively broad leaves. The next type of savanna has 60 to 80 cm of rain and the trees are mostly deciduous with about 50 per cent of them having small or finely divided and thorny leaves such as the acacias. Finally the type of savanna found near deserts, often known as thorn savanna has rainfall of between 40 and 60 cm with an intense dry period. The trees are very sparse, small and thorny with rather reduced leaves.

Factors of the Habitat

(*a*) *Rainfall:* As already indicated above the amount of rainfall determines the type of savanna that is formed. Thus rainfall is a very important factor here.

(*b*) *Fire:* Fire reaches most parts of the savanna every year during the dry period. The fire may be started by farmers when clearing the land for farming.

Hunters may also use fire to drive out animals from their holes and hidings. It appears that the fires stimulate the regrowth of some perennial plants from their underground buds. While they damage some species of trees, they fail to damage others that are fire-resistant because of their thick barks.

(*c*) *Animals:* The grasses form a natural habitat for large numbers of hooved grazing animals. They also harbour the large carnivores, like the tigers and the lions, which prey on the herbivores. These animals exert much influence on the vegetation.

Activities of Man

The savannas are notable areas for cattle and sheep rearing. Farming of cereals like maize, millets and guinea-corn is widely undertaken. Vegetables are also grown extensively during the rainy season. The farmers often live in homesteads and, where the dry season is long (as much as seven months), numbers of the people often migrate to the forest zones for casual employment during such periods and return, some to farm when the rains come. The low-lying undulating nature of the land makes the tropical savannas potential areas for mechanized agriculture, and provided irrigation can be practised their potentiality will exceed all expectation.

Tropical Deserts

The vegetation of tropical deserts consist of widely scattered thorny bushes as well as some succulents like the Cacti and Euphorbias. In places, as in the oases where, as a result of little rain in a very brief period, certain small short-living plants (*ephemerals*) grow and complete their life-history in a few weeks. One of these, *Boerhaavia repens* is able to germinate and bear fruit in a matter of ten days.

The thorny bushes consist of plants with very small leaves. Some even have no leaves at all. These plants have many other characteristics of plants associated with dry places (*xerophytes*) among which are sunken stomata, presence of a corky layer over the stem and a large amount of strengthening tissue. The succulents are fleshy plants that hold a lot of water in their tissues and lose very little of it even under dry conditions of the desert.

Habitat Factors

Water: Water is evidently the greatest limiting factor to the growth of plants in the desert. The low rainfall of about 25 cm a year falls in a rather unpredictable fashion and some parts of the desert may have no rain for a year or more. When the rain comes, it falls so rapidly that much of it runs off the ground.

The scarcity of water as well as the dryness of the atmosphere which is often clear of clouds and therefore very sunny have combined to exert much influence on the structure of the plants. These factors, some of which have been enumerated above, include the development of extensive root-systems which are out of proportion to the small size of the plants. The large root system makes it easy for the plant to absorb water from a large volume of the soil.

The critical importance of water in the desert is shown by the presence of more permanent and relatively luxuriant forms of plant and animal life in the cases where underground water exists. This means that the deserts are by definition not 'poor' areas. If water is made available, vegetation readily grows except in the stony or bare areas where the surface soil has been removed by strong winds. Indeed many of the deserts have been found to be rich in minerals and oils.

Animals: Only the camel seems to have survived in the desert as a beast of burden because of its ability to utilize very little water in the course of its life.

Activities of Man: A limited range of sheep may be reared in oases where settled life is found. Date palms are also found among the most economic plants here. The discovery of minerals and oil deposits has led to some active mining activities in the deserts.

Some Minor Terrestrial Habitats

(*a*) *Strand* (*the Seashore*): Apart from the desert, the sandy seashore is the most unfavourable within the terrestrial habitat for life in the tropics. Firstly, the sand is well drained and hence retains little water, and even if it is not wholly dry the water is not easily available to the plants, since it is highly saline. Secondly, winds are usually strong and, as we have learnt, this increases the rate of transpiration excessively. Only plants that are adapted to withstand such conditions are found. Such plants often have thick and reduced leaves (as in *Sesuvium*), hairy leaves (as in sea-side lavender *Tournefortia*), or leathery leaves (as in *Ipomoea*), so that they do not have excessive transpiration. A number of the plants also trail on the ground and are rooted at the nodes (as in species of *Ipomoea*); by being low and spreading they are less exposed to the wind. Other plants have long roots to tap water which

may only exist deep down in the soil. The coconut palms may be planted by man, and are able to withstand the wind by means of their strong, fibrous roots.

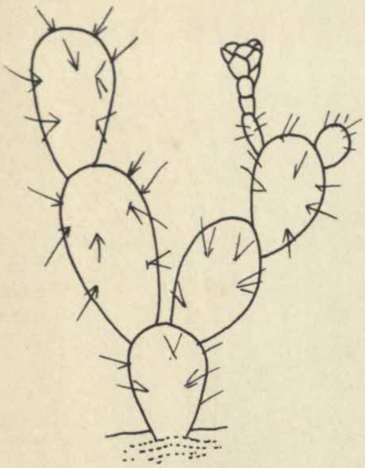


Fig. 3.15. *Opuntia*

As the wind blows the dry sand, it forms sand-dunes, which are held together by creeping plants like the sea-side morning glory (*Ipomoea biloba*) and the purple sea-side bean (*Canavalia obtusifolia*), as well as the binding grass (*Paspalum*) or *Remirea maritima*. *Ipomoea* and *Canavalia* creep along, branching at the nodes to form a thick cover on the sand. They also have long roots. Among the larger plants is the screw-pine (*Pandanus*), which is a shrub remarkable for its large prop-roots that help to anchor it in the sand against strong winds. There are a few characteristic animals found in this habitat. These include the ghost-crabs and some spiders and scorpions. Turtles are less frequently found, while lizards and snakes may occasionally be seen.

As we move away from the sea, the vegetation gets denser and more stunted. It includes species of prickly pear (*Opuntia*) (Fig. 3.15), the bellyache bush (*Jatropha gossipifolia*), *Thespesea populnea*, and the carrion crow bush (*Cassia alata*). Among the animals found here are rats and ground lizards.

(*b*) *Abandoned Farmland:* There is no end to the nature of the ground-level habitats that can be met in practice. In the tropics the principal vegetation types are the tropical forests, the savanna and the desert. The type of plants and animals to be met depends on the principal vegetation type within which the habitat falls. There will be too much to say on each of these vegetation zones, and this will not be done here since the material is available in a number of geography books which the student can consult.

Here I shall choose a very limited example of an abandoned farmland to illustrate the stages found when a forest farm is abandoned. This type of succession which starts on an area that has had vegetation or life on it before is referred to as secondary succession as opposed to primary succession where the stages start from scratch on an area that has never supported life (see Chapter 2).

When a farm is abandoned, various plants and animals begin to recolonize it. Among the first plants to be found are those from cut stumps and those from rhizomes like the nut-grass (*Cyperus rotundus*) in the soil. There are also annuals like *Cleome* and *Tridax*. On the leaves of some of these plants may be found the caterpillars of butterflies.

Soon creeping grasses and low bushes follow. In West Africa these include plants with light and easily dispersed seeds like *Musanga smithii* and *Trema guineensis*. Finally, trees from seeds of plants like the mango, pawpaw, and other fruit-plants appear. After some years a tangle of impassable vegetation may be produced.

The Arboreal Habitat

The arboreal habitat is typical of the tropics. Although a few fern epiphytes are found in temperate vegetation, the situation bears no comparison to the profuse growth found on trees in the tropics consisting of bryophytes, ferns and flowering plants. The arboreal habitat

is like other terrestrial habitats in that plant and animal life develop progressively on the tree-trunks through stages similar to those on land.

The arboreal habitat develops on trees with rough surface of the stem such as the oil-palm. Trees with smooth surfaces have only the junctions of the branches for developing the arboreal habitat. The rough surface or the branch junctions anchor rain drops and the small portions of the bark and the other debris. Gradually soil particles collect in the pockets and this provides a suitable substratum for the colonizers. These are usually crustose lichens. They survive under these difficult conditions and as some of them die, they add their remains to the soil, thus modifying the latter to the extent that it becomes suitable for mosses which begin to appear. The mosses also help to modify conditions and ferns like *Platycerium* and *Polypodium* enter later. These ferns are more resistant than *Nephrolepis* and *Microgramma* which are able to enter later after the habitat has been modified by the *Platycerium*. Later flowering plant epiphytes such as orchids appear.

Light is a limiting factor here due to the shade cast by the forest trees. Humidity is also high except at the very top of tall trees where special sun-epiphytes are found.

The resistant fern *Platycerium* (Staghorn fern) (Fig. 3.16) seems to be interestingly adapted. Its leaves are rather broad and leathery and are of two kinds, each of which is adapted for a separate function to suit its habitat. The dead brown shield-like leaves which are pressed against the trunk serve the function of collecting water as it trickles down the trunk. In this water are dissolved salts from the decayed remains of other dead epiphytes and small portions of the bark of the tree. The decayed remains collect at the bases of the brown leaves and serve as a reserve supply of mineral salts for the fern. The green leaves which protrude from the brown leaves are able to manufacture food by photosynthesis. These leaves are described as fertile fronds because they bear the spores in small groups seen as brownish spots on the under surface of the leaves.

The epiphytic orchids (Fig. 3.17) are successful in the arboreal habitat for a number of reasons. The seeds of these orchids are among the smallest found in flowering plants and can germinate and survive in difficult conditions. They also have long spongy roots which absorb drops of water which trickle down the trunk. Some of the roots contain chlorophyll and thus manufacture food for themselves. The upper part of the roots also offer attachment by spreading widely over the host plant and clinging to the bark, while the lower portions hang freely in the air to collect the drops of water. Since the air at the upper parts of the trunk is often drier, the leaves of the orchids are thick and leathery and thus check excessive loss of water by transpiration.

How and What to Study in Communities

Before making an ecological study of the community in a habitat, you need to define the location of the area as well as the date and time of the study. You then have to determine the size of the area. Now the shape of the area may be irregular and so you would have to use simple

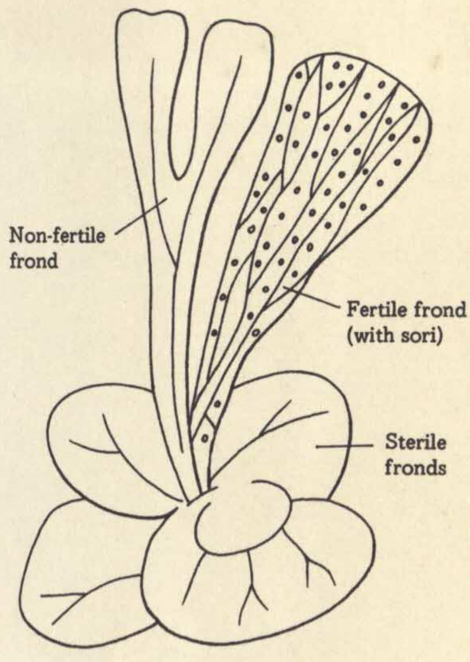


Fig. 3.16. *Platycerium*

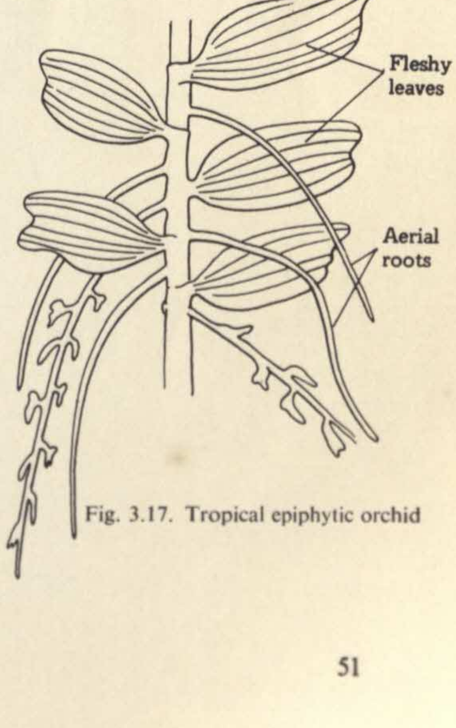


Fig. 3.17. Tropical epiphytic orchid

field methods to determine the area. This is not always necessary if the area is rather large, but if it is not large and you wish to determine its size you can use the method described under the Suggested Practical Work at the end of this chapter.

The next important work is to make a general list of the plants and animals commonly found in the area. This will not be complete since you will find a few more plants and/or animals when you come to make the closer study of parts of the area. In preparing the list of plants and animals it is necessary also to make notes on the behaviour of each of the animals in the habitat, such as whether it is a permanent resident in the habitat by reason of feeding or breeding or whether it is only a visitor to the area. With plants it is necessary to note the state of growth, whether they are flowering or fruiting, whether they are seedlings or mature, and whether they are growing vigorously or dying out.

If the area is fairly small it is possible to count the number of each of the plants and animals there and to classify them, but in most cases the area under study may be rather large. In that case it is humanly impossible to count every individual organism, and this is where we need to find a way of getting a fair picture of the composition of the community without counting everything in the area. The method used for this purpose is referred to as *sampling*. The object is to take a sample which constitutes a small fraction of the community and to examine closely the composition and features of this sample. In order that the picture obtained from the sample may be very much like that of the entire community under study, the sample must be truly representative of the whole community, otherwise the effort put into the work would have been wasted because conclusions based on the observations made would prove untrue when compared with the whole population.

It is therefore most essential in using the sampling method to avoid, as far as possible, any bias or personal element. The processes of sampling should therefore be objective.

The sample usually consists of a repetition of several standardized units. The standardized units are of different forms. In plants it takes the form of what is called a *quadrat*. This is often a square (although it can be of some other shape) of convenient size made of wood or stiff wire. In order to get a sample without bias, the quadrat is thrown at random behind one's back a number of times. Wherever it may land on each occasion the representatives of every plant species within the quadrat are counted. The species of animals may also be counted. The sample here consists of the area of all the tosses made on the community under study.

It should be noted that there are many other ways of obtaining a sample. For example if you wish to get an idea of the extent to which a large *Ficus* tree is infested with insects, say termites, during one season the sample may consist of say 20 units, each unit being a leaf of about the same size taken at random from different parts of the tree. The number of termites per unit (each leaf) is counted separately and the whole sample consists of all the 20 leaves or counts. Now in order to arrive at the extent of infestation of the tree you have to get the average

area of the 20 leaves. You can get this by tracing the leaves on graph paper and counting the area in a manner similar to what you do with finding the area of a chosen habitat referred to above, and described under the Suggested Practical Work at the end of this chapter. Here of course you should multiply by two to get the area of both sides of each leaf.

Let us assume that the observations made on the number of termites on each of the leaves and the sizes of each of the 20 leaves were as follows:

Leaf	1	2	3	4	5	6	7	8	9	10	11	12
No. of termites	55	48	47	43	55	65	44	49	43	67	48	44
Area of leaf in cm² (both sides)	20	26	25	24	15	21	20	29	21	28	14	17

Leaf	13	14	15	16	17	18	19	20	Total	Average
No. of termites	48	57	59	43	68	42	44	41	1010	55·0
Area of leaf in cm² (both sides)	15	19	20	21	21	17	28	14	415	20·8

Now the average number of insects per leaf is obtained by dividing the total number of insects by 20 (which is the total number of leaves), and that is 55·0 (say A). Again the average area per leaf is obtained by dividing the total area by 20 and that is 20·8 sq. cm (say B). Thus the number of termites per unit area of the leaf on the tree is $\frac{A}{B}$—i.e. **2·7.**

Now this evaluation of how many of the termites exist on the *Ficus* tree as estimated here is in ecological terms, called *density*. Here we determined the density of termites on a *Ficus* tree. The density of a given species is defined as the number of the species present in a unit of a habitat. It is an expression of the *abundance* of the species in question.

By repeating the above experiment at another season of the year, say the rainy season, we shall be able to determine whether the abundance of the termites has increased or decreased. In this way we are

able to say which weather is more favourable to the reproduction and growth of termites on the *Ficus* tree.

It may also be that there is more than one insect on the *Ficus* tree. If we are then interested in the density of both insects, then we could have counts of both insects on each leaf. In this way we can compare to find out which of the two insects is more abundant.

To return to the use of quadrats in plant communities, we will find that the same principles as described for insects on the *Ficus* tree are applicable here.

It is common in plant communities in the tropics to have quite a number of plant species in even a fairly limited habitat. For the beginner it would be enough to study one or two of these species in the habitat rather than all of them. In that case if you wanted to estimate say the abundance of say *Acanthospermum* and *Tridax* in a given habitat, all you do is to concentrate on these two species when making counts in each of the quadrats you blindly throw on to the area under study. Here the area of the quadrat is already fixed, and so there is no need to go through any elaborate process to get the area. Assume you made 20 throws of the quadrat of size 1 metre^2 and obtained the following observations:

No. of throw of quadrat	1	2	3	4	5	6	7	8	9	10	11	12
No. of *Acanthospermum*	2	3	4	5	2	1	8	3	2	1	7	2
No. of *Tridax*	5	9	8	8	10	6	7	9	5	6	7	9

No. of throw of quadrat	13	14	15	16	17	18	19	20	Total	Average
No. of *Acanthospermum*	1	2	3	4	8	2	1	2	63	3·2
No. of *Tridax*	9	8	2	7	5	3	8	10	141	7·1

Here the abundance of *Acanthospermum* is given by the density—i.e. 3·2 per unit metre^2, and that of *Tridax*—i.e. 7·1 per unit metre^2. You can thus compare the abundance of these species on, say, different physiographic elevations.

You may have formed an idea about the nature of the plants in the habitat from the size of the quadrat used here, that is, the 1 metre^2 quadrat. Of course if you already know *Acanthospermum* and *Tridax* then you will understand this. Naturally however you cannot expect to be able to use a 1 metre^2 quadrat on an area consisting of shrubs or trees, because you may not get even one of them into that quadrat. In view of this, there are different sizes of quadrats which can be used in different types of vegetation. Thus in communities of herbs and grasses a metre^2 quadrat is used, and in communities of shrubs a 4 metre^2 quadrat, and finally for trees, as in the forest, a 10 metre^2 quadrat is used

Permanent Quadrats

You may wish to repeat your studies of particular species of plants throughout the year in order to note what changes occur in the growth, multiplication (increase in density) and distribution of the species at different times of the year. In such a case you need to mark permanent quadrats on the area of study, since you cannot throw the quadrats every time you want to take readings. The choice can be made on a map of the area (as described under the Suggested Practical Work at the end of this chapter) can be made for you by your teacher using methods that will avoid any bias in the choice. In intensive studies on permanent quadrats it is possible to include the study of environmental factors of the area, such as temperature, rainfall, etc.

Phenology

The changes which one can observe in the growth behaviour of plants during the year in particular species of plants (as in the study of permanent quadrats) in the tropics can be quite interesting. The relationship of the growth behaviour of the plants at different periods of the year cycle in relation to the weather conditions of the habitat is known as *phenology*. For a chosen plant or plants of the same species the following are some of the aspects of growth behaviour to be watched during the year cycle:

(*a*) Seed germination: The month of the year during which the seed germinates, the rate of germination, the period between the time the seeds were shed from the fruit and the time of germination, that is, dormancy period, etc. Seed germination will not be necessary in perennial plants which would already be in the habitat.

(*b*) Emergence of new leaves: Time of emergence of new leaves on the plant in relation to the time of flowering, that is whether before or after flowering.

(*c*) Leaf-fall: Does the plant lose some or practically all of its leaves at some period of the year? If so in which month or months does this happen?

(*d*) Flowering: The time or times of flowering in the year and the period over which flowering is spread. The agent responsible for pollination.

(*e*) Fruiting: The time or times of fruiting in the year and the duration of each of the fruiting periods. The amount of the fruits

produced. The agent for fruit dispersal and how far from the plant the fruits are dispersed.

(Some observations on the phenology of some common tropical trees is given in Chapter 23.)

Conservation and the Control of Pollution

Conservation is the wise use of the resources of nature. It is aimed at keeping the exploitation and other actions of man (such as pollution) that are harmful to the ecosystem at such a level that a balance is maintained between the various parts of the ecosystem; this is to enable the ecosystem to be able to renew itself continuously and so be able to continue to provide man with what he needs from nature.

From what has just been said about conservation, it is obvious that it does not mean putting a stop to the use of the resources of nature, as is often assumed. It permits the use of the resources of the ecosystem but at such a rate and in such a way that it is not destroyed. To use a simile from the financial world we would say that conservation makes it possible to remove the yearly interest on a savings account without removing the original capital.

In the advanced countries the increase in man's industrial activities has led to such pollution and destruction of ecosystems that conservation has become a serious matter. In the developing countries, however, people have for some time now looked round and felt that they still had a long way to go before they had the same problems. The situation has cnanged rapidly and now they have the same problems of pollution and destruction of natural habitats. Knowledge of conservation is thus a prime necessity for developing countries. The gravity of the problem of conservation has been well put by Walter C. Lowdermilk, who has composed what he terms the Eleventh Commandment as follows: 'Thou shalt inherit the holy earth as a faithful steward, conserving its resources and productivity from generation to generation. Thou shalt safeguard the fields from soil erosion, thy living waters from drying up, thy hills from overgrazing by the herds, that thy descendants may have abundance for ever. If any shall fail in this stewardship of the land, thy fruitful fields shall become sterile stony ground and wasting gullies, and thy descendants shall decrease and live in poverty or perish on the earth.'

We shall now consider the various aspects of conservation with reference to the various parts of the ecosystem.

Soil

Soil holds the key to the stability and functioning of the ecosystem because of the decomposers it contains. If the vegetation on the soil is removed, it becomes exposed to heavy rains which erode the topsoil with its humus which contains the decomposers. When this happens the remaining soil can no longer absorb water which consequently runs off. The original fertility of the soil is lost for ever.

Modern agriculture has made it possible to use such soil through the supply of artificial fertilizers and pesticides. However pesticides, like DDT, Aldrin and Dieldrin persist for long periods in the soil and in

the other parts of the ecosystem including the plants and the animals. These pesticides are now being used on an increasing scale in many developing countries on their cash crops, such as cocoa in Ghana. The aim of conservation here is to find pesticides which do not persist long in the soil.

Forests and Agriculture

The tropical forests, for example, have taken millions of years to reach their present stable state as an ecosystem. It will be impossible to replace them once we have destroyed them. In many developing tropical countries the forests are fast disappearing. This is largely due to increased agricultural practices following increases in population and the development of the timber trade. Most of the minerals and the energy of the forest are locked up in the timber, so that their removal constitutes drastic injury to the ecosystem. It is therefore necessary for the exploitation of the forests to be carried out in such a way that they are preserved without permanent damage.

One of the best ways to obtain timber from a forest in perpetuity is to manage it on a *sustained yield* basis, that is, by replacing every tree removed by another. Felling must be highly selective, and phased in such a way that the forest is maintained in as natural a state as possible. There is also the need to industrialize the exploitation of timber in the tropical countries in order to improve its efficiency and put an end to the wasteful practices by which much timber is felled and left to rot.

Another important aspect of this is to protect agricultural productivity. Many of the tropical tree crops such as cocoa, rubber and coffee require high fertility and forest cover, so that as the forests are lost, the cultivation of these crops will become more difficult.

Wild-life

The term *wild-life* has come to be used to refer to the game vertebrates. Conservation of wild-life however implies the conservation of the ecosystem of which the game animals form a part. Thus the destruction of forests and other natural habitats goes with the disappearance of the wild-life of these habitats.

The rapid rate at which wild-life is disappearing in some parts of the tropics is alarming. In most of West Africa, for example it is only fifty years since large areas were teeming with game such as elephants, antelopes, buffalo, hartebeest, waterbuck and several other large grazing mammals. Many of these have already been exterminated by hunters who killed for 'sport' during the colonial era, and by the tsetse control workers in a futile attempt to eliminate that pest. Now much poaching goes on for the meat of the animals and the hunters thoughtlessly shoot even the young and the pregnant females.

The commercially successful efforts in East Africa show the benefits which can be derived from conservation and planned grazing of wild-life for meat. The great herds of grazing mammals of East Africa are one of the wonders of the world, containing an extraordinary variety of species in balance with their environment. Apart from serving as a tourist attraction to the world, they are potential sources of wild meat

and other products such as milk. This is a cheap way of reducing protein deficiency.

In many tropical countries, with special reference to East and Central Africa, Game and National Park Ordinances have been established to provide a legal basis for wild-life management. The general aims of these Ordinances are as follows:

1. To conserve some of the unique wild-life of the region, especially the larger wild animals, as samples and to preserve the natural vegetation, especially any unique flora of the country.

2. To conserve all features of special geological and geographical interest, and outstanding natural scenery.

3. To set aside a number of large areas where wild-life and wild scenery can be enjoyed by the local people and visitors.

4. To establish a number of Nature Reserves which would aim at preserving rare species of animals or plants, as well as serving as a sample of all the natural habitats of the region to facilitate their study.

5. To promote close links of conservation with scientific and research organizations, and with all levels of the educational system of the country.

There are four types of organization of wild-life management, as follows:

(*a*) Strict Nature Reserves for complete protection of nature in the wild. Human influence is completely excluded in these areas.

The Strict Nature Reserves are unique. Where it has been successful even in excluding the effect of fire and from other human interference, this has in some instances resulted in bush land having replaced the grassland. Animals like elephant, buffalo and bushbuck, which prefer living in the bush, have grown very numerous, while the animals that like open grassland, such as the antelopes, have declined in number.

(*b*) National Parks may be developed for public enjoyment by the provision of facilities such as roads or camping sites.

In some National Parks, water supply points are provided for the wild-life. Also, controlled burning and other forms of land management are used to ensure that a certain minimum number of animals is maintained. National Parks have also resulted in vast increases in numbers of otherwise scarce animals, which have also become rather tame and appear to be unworried by traffic near them. National Parks provide opportunities for ecological studies of the wild-life.

(*c*) Game Reserves are like National Parks but less permanent. Hunting is not permitted and thus affords wild-life free movement. Boundaries are subject to alteration and Game Reserves are often without the usual amenities provided in National Parks.

The Game Reserves offer protection for much of the wild-life in the sparsely-inhabited areas outside the National Parks. They also act as feeders to National Parks.

(*d*) Controlled Areas where hunting is permitted but only for licence holders.

Controlled Areas ensure that by limiting the rate of killing of defined numbers of particular species of animals in remote grazing and browsing areas, the stock of animals is increased systematically. Apart from these, there are a few Open Hunting Areas with relatively less game where hunting is permitted by game licence.

Much information is still needed about wild-life and its needs if its management for the benefit of man is to be made more efficient. In many tropical countries, research is needed to provide the information required. We need to know a lot more about the numbers of different species of animals in a habitat, their grouping, migration, feeding and other habitats. We also have to ascertain the potential sources of protein in wild-life, of different habitats, their destructive habits, the diseases and pests they harbour and transmit to man, and finally their effect on the use of land in the particular habitats.

Water Resources

The organo-chlorine pesticides, such as DDT, Aldrin and Dieldrin which are long-persistent in soil and vegetation are eventually drained into lakes, rivers and streams where they can poison fish.

The use of fertilizers also creates similar problems in that they dissolve in rain water, and it is impossible to prevent some percolating through to rivers and streams through the drainage systems of the soil. Nitrates and phosphates are two of the main constituents of those fertilizers and when they are added to rivers and lakes they cause drastic changes in which many of the more desirable elements of the flora and fauna die off, and in particular, fish are unable to survive.

Developing countries have great problems preventing such occurrences as have taken place in the advanced countries. In these countries we find some of the world's largest lakes suffering from pollution. Lake Eyrie in the United States, for example, has become almost useless for fishing, even though it was once a valuable fishery. Even remote lake Baikal in Siberia is suffering from pollution.

Another major source of pollution is crude oil. Leaks from tankers are becoming more frequent and off-shore drilling rigs have caused bad spillages, notably in Santa Barbara in California. The problem is still real in a number of developing countries where off-shore oil has been discovered.

There are many other industrial wastes which get into water. A number of developing countries have within the last thirty years made man-made lakes primarily for hydro-electric power but also for irrigation, agriculture, fisheries and transport. Without keeping the water clean it cannot be used for fisheries and irrigation agriculture. Examples are the Aswan High Dam in Egypt and the Volta Dam in Ghana. With increasing use of fertilizers it would be all too easy to wreck these dams as a habitat for fish before their immense potential as a food source is developed.

Air

We often forget the air as one of the essential biological natural resources of man. Pollution of soot and smoke from industries has made the air in some industrialized countries unclean for man and

other animals. Although this seems to be a distant problem to developing countries, it is worth bearing this in mind in planning future industrial policies of the newly developing countries.

Conclusion

The problems of conservation which face tropical countries are immense and moreover, these resources are intimately interrelated and inter-dependent. Hence their solution is to be seen in a total approach and not on single-project basis. This requires careful consideration and the need to seek advice. But the trouble is often that developments are not thought through to their logical conclusions before they are begun, and the experts in ecology are brought in to clear up the mess when things begin to go wrong. In many tropical countries these problems are also beset with a mixture of ignorance, apathy and ruthless exploitation for personal gain.

There are no easy solutions to these problems. To reverse or even halve the present catastrophic race to destruction will involve a major effort in education, law-enforcement and rethinking of traditional ideas.

The biosphere belongs to all mankind, and everyone should contribute his voice against pollution of the biosphere. It is the duty of the major industrial countries to control this pollution, and newly developing tropical countries should make constant protests against pollution at the United Nations and other places to galvanize the advanced countries into action, so that the overall environmental deterioration that is occurring might be brought to an end.

SUGGESTED PRACTICAL WORK

1. Ecology is essentially an out-door subject, and every effort should be made to make frequent visits to a chosen area.

Mapping the Area: It is sometimes useful not only to map an area under study but also to locate it in such a way that it may be easy to find it at any time. The location could be done by means of measuring tapes, compasses and permanent stakes. The map made of the area which may be of any irregular shape can also be made by locating certain permanent objects and distinct vegetation boundaries.

The map can be as simple as possible and may be made by the baseline and offset method for a reasonably sized area. In this method a straight line is first run across the area by means of three vertical poles spaced one at each end and one in the middle.

This line is referred to as the baseline AB intersected at right angles by another line XY, also a baseline. The right angle can be ensured by using a cord triangle measuring 3 m $\times$ 4 m $\times$ 5 m. Pegs are then driven into the soil at equally spaced (and suitably chosen) intervals, beginning from the point of intersection of these two lines parallel to each of them right to the edge of the area under study. Offset is at right angles to either of the baselines. In this way the area gets divided up into squares each bounded by pegs, and if the data are plotted to scale on graph paper, a map is obtained whose area is easily calculated.

After a thorough study of the area it is possible to make a vertical projection of the plants occurring in the area to obtain a surface map of the distribution of the plants (cover).

2. Determination Density of Different Plant and Animal Species in a Chosen Habitat by a Class:

1. You are supplied with a list of one plant and one animal species (see below) which is typical of the chosen area. Specimens of these species will be displayed in the laboratory to enable you to be reasonably familiar with them before you set out for the field work.

2. The list of species below shows a series of columns one for each toss that will be made with the quadrat.

3. You are to work in pairs, and each pair should be assigned only one of the species for study.

4. Throw the quadrat freely (and without bias) on to any part of the chosen area. With each toss count the total number of plants of the species assigned to you which occurs in the quadrat, and record the number opposite the name of the species on the species list.

5. Each pair of students should make ten tosses of the quadrat.

6. At the end of the ten tosses return to the laboratory and collect the records obtained by nine other persons who worked on the same species and tabulate these records along with yours so that you have the results for 100 tosses.

7. Work out the density per quadrat (or unit cm^2) for the species.

No. of Plants or Animals of each Species in each Toss

Tosses	Plant Species	Animal Species
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
Total		
Density		

Tens of Tosses

Tens of Tosses	Plant Species	Animal Species
1st		
2nd		
3rd		
4th		
5th		
6th		
7th		
8th		
9th		
10th		
Total		
Density		

3. Phenology. It is very important to keep a careful record of the observations you make at each visit. Note the seasonal changes that occur in the plants and animals in a special note-book kept for ecological studies.

Supplement these notes with drawings and paintings. Below is an example of how you may keep your record for the year. You should spread this over the left and right sides of your open note-book, so that you have enough space under each month to record your observations. You can use abbreviations.

Phenological Chart

	Mango	Palm Tree	Ceiba Tree	Termi-nalia	Any others
January					
February					
March					
April					
May					
June					
July					
August					
September					
October					
November					
December					

Make sure that in your note-book you always record the date of each observation.

CHAPTER FOUR

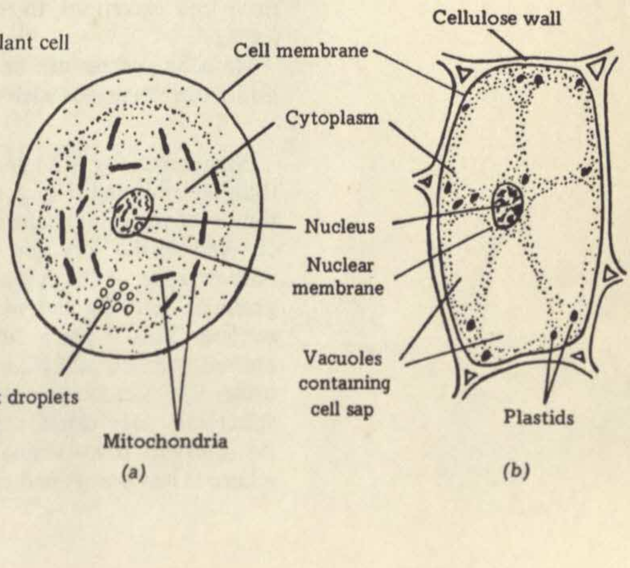
Cells and Microscopic Animals

MICROSCOPIC animals are animals which are so small that they cannot be seen with the naked eye, but only with the aid of the microscope. In its simplest form a whole organism appears to consist of only a single cell, but since it performs all the functions of an organism it is not proper to refer to it as unicellular, so we say that it is *acellular* or *non-cellular*. Our main examples of acellular animals will be *Amoeba* and *Paramecium*, but we shall also make some mention of *Euglena*. There are also other microscopic animals, such as *Hydra*, whose bodies are made up of numerous cells: these are said to be *multicellular*.

Before we study these forms of lower animals, we need to learn something about the structure and physiology of a cell as found in a multicellular organism. This will help us to understand the nature of the microscopic animals.

Before the seventeenth century, biologists had to rely on the naked eye alone for the observation of living things. Since the invention of the *microscope*, an instrument which magnifies any object viewed under its lenses, it has become possible to examine not only the microscopic animals we shall describe, but also the minute anatomy of all animals and plants. It has been found that every living organism is composed not of an undifferentiated mass of jelly-like protoplasm, but of single units of protoplasm in tiny compartments called *cells*. Each cell (Fig. 4.1) is surrounded by a cell-membrane outside which the protoplasm may secrete a wall—for example, the cellulose wall of plant cells. As we have indicated before, animal cells have no such rigid cell-wall. The protoplasm of the cell generally consists of a denser part called the

Fig. 4.1. Cells: (*a*) animal cell; (*b*) plant cell



nucleus surrounded by a less dense part called the *cytoplasm*. The cytoplasm contains many *granules*, some of which are often food substances such as fat droplets. In some animal cells the outer part of the cytoplasm is seen to be without granules. As the cell grows, spaces full of fluid (cell-sap) often develop in the cytoplasm; these spaces, called *vacuoles*, are common in the adult plant cell and are rare in animal cells.

Modern investigations have revealed the structure and functions of the different parts of the cell. The cell-wall of the plant cell is permeable to chemicals in solution; but the cell-membrane of both plant and animal cells is *semi-permeable*—that is, it allows water to pass through into the cytoplasm but stops the substances dissolved in the water. The cytoplasm is the part of the cell in which the majority of the various chemical activities of the cell are carried out, with the aid of certain organic catalysts called *enzymes*, which are substances which hasten the rate of reactions. The enzymes are mainly found in rod-like bodies in the cytoplasm known as *mitochondria*. A study of the nucleus shows that most cells without a nucleus cannot reproduce or grow. The nucleus contains a high proportion of substances called *nucleic acids* which are probably prevented from passing into the cytoplasm by the *nuclear membrane* which surrounds the nucleus. It is the nucleic acids which control growth, reproduction, and other chemical activities of the cell.

Let us now consider some of these acellular organisms which, according to the classification of animals, form the group known as *Protozoa*.

Amoeba

The common amoeba is known as *Amoeba proteus*. It is probably one of the simplest living animals, as it is a single cell with nucleus and cytoplasm, and without any visible part of its body set aside for performing special life processes, such as movement. Yet, in spite of its seeming simplicity, it performs all the essential activities of a living organism; it is able to move, to capture, digest, and assimilate complex food, to throw out indigestible residues, to respire, to produce secretions and excretions, to respond to stimuli, to grow, and to reproduce its kind.

Amoeba proteus can be collected from the surface of mud in ponds and from situations such as the surface of submerged dead leaves.

Structure. (Fig. 4.2.) *Amoeba* is of microscopic size, generally not more than 0·6 millimetre long. It is a mass of colourless jelly-like protoplasm that is of irregular shape and frequently changing in form. The body is covered with a very thin elastic cell-membrane. Beneath this is a clear narrow zone of the cytoplasm (called *ectoplasm*) surrounding an inner granular part (*endoplasm*). Within the endoplasm is the lens-shaped *nucleus*. This is often difficult to see in the living animal; but if the animal is killed and stained with certain dyes, the nucleus can be seen under the microscope as a darker body. The endoplasm also contains a spherical space called a *contractile vacuole*, which is filled with fluid. At intervals this vacuole increases in size and moves to the surface, where it lets out its contents into the surrounding water, after which it

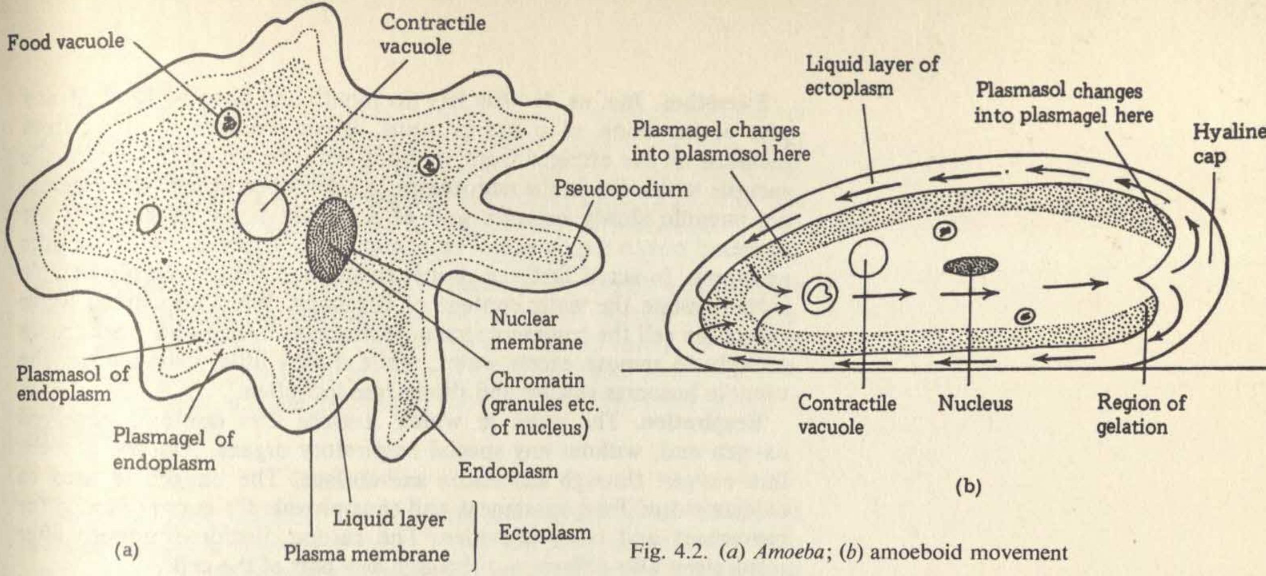


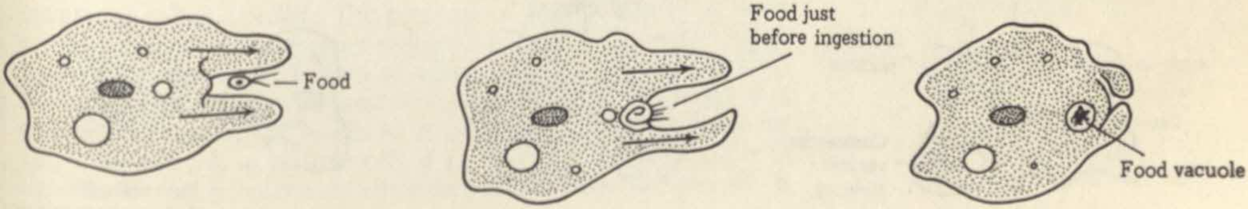
Fig. 4.2. (*a*) *Amoeba*; (*b*) amoeboid movement

begins to re-form. Other contents of the endoplasm are *food-vacuoles*, crystals, and other substances.

Movement. When *Amoeba* is moving along it forms temporary finger-like extensions or lobes at any part of its body. These extensions are called *pseudopodia*, or 'false feet'. During the formation of the pseudopodia, the thicker ectoplasm in front of the pseudopodia becomes more flexible, allowing the more fluid endoplasm to flow forwards into these projections. On reaching the front, the endoplasm becomes more solid, forming ectoplasm. At the 'back' of the animal, the ectoplasm liquefies and gets converted to forward-flowing endoplasm. (See Fig. 4.2.) In this way *Amoeba* progresses by a sort of flowing movement, as though it were rolling over on itself, forming pseudopodia in one direction while withdrawing those behind. This method of movement is typical of *Amoeba* and has earned the name *amoeboid movement*.

Feeding. *Amoeba* feeds on other micro-organisms, such as flagellates and ciliates, bacteria, and algae, or the dead remains of larger animals such as nematodes and rotifers. It feeds with the aid of the pseudopodia, and food can be taken in at any part of the body (Fig. 4.3). On making contact with its prey *Amoeba* extends pseudopodia to encircle it. The food is first taken into the body with a bubble of water to form the food-vacuole. Some kind of digestive juice is secreted by the cytoplasm into the food-vacuole to help in digesting the food, after which the digested food can be assimilated. Indigestible material is left behind when the food-vacuole breaks at the surface and the amoeba moves on.

Fig. 4.3. Feeding processes of *Amoeba*



Excretion. Just as *Amoeba* has no mouth and absorbs food at any part of the body, so it has no anus. Waste products resulting from metabolism are excreted from its body with the aid of the contractile vacuole which lies in the endoplasm. As described above, the contractile vacuole slowly enlarges and at a certain point its contents are squeezed out to the outside. The contents are largely water plus a little ammonia. In actual fact, the proper function of the contractile vacuole is to regulate the water content of the body. When too much water enters the cell the contractile vacuole increases in size and works more actively to remove excess water, while if very little water enters, the vacuole becomes smaller and discharges less often.

Respiration. The water in which *Amoeba* lives contains dissolved oxygen and, without any special respiratory organs, *Amoeba* absorbs this oxygen through the entire cell-surface. The oxygen is used to oxidize stored food substances and thus provide the energy needed for movement and other activities. The carbon dioxide produced after respiration also diffuses out through any part of the cell.

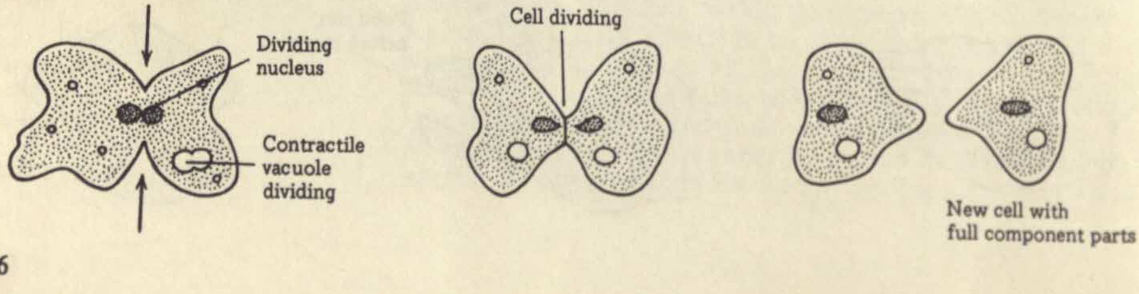
It is interesting to prove experimentally that *Amoeba* needs oxygen. When living amoebae are placed in already boiled but cold water (which does not contain dissolved oxygen) they lose nearly all their activity owing to lack of energy, and may later disintegrate through death of the protoplasm.

Response to Stimuli. *Amoeba* shows response to both internal and external stimuli. It responds to the internal stimulus of hunger by searching for food. It also responds to the external stimulus of contact with food by sending out pseudopodia to capture it. When an amoeba is touched with a fine needle it contracts into a ball but when it is floating and touches another object, it fastens itself to it. *Amoeba* withdraws from strong light and strong chemicals, although it will move towards substances diffusing from its food.

Growth. The food materials assimilated by *Amoeba* during feeding are used in forming fresh protoplasm. As more and more protoplasm is formed in this way, the amoeba grows until a certain maximum size is reached, when it begins to divide.

Reproduction. There is no sexual reproduction in *Amoeba* and the method of reproduction is *asexual*—that is, it does not involve two cells or their products fusing together. Instead, the mature animal proceeds to divide into two by a process called *binary fission* (Fig. 4.4). The nucleus becomes long and divides into two equal halves by a process known as *mitosis*. At the same time the cytoplasm around the nucleus also divides into two, so that at the end of binary fission we have two amoebae, each with its own nucleus and cytoplasm.

Fig. 4.4. Binary fission in *Amoeba*



The process of binary fission goes on all the time when conditions are favourable, but when conditions become difficult as, for example, when the pond begins to dry up, the amoeba assumes a rounded shape and secretes around itself a horny protective covering called a *cyst*. In this form it can prevent further loss of water from its body and can be blown about. In this way *Amoeba* can reach new ponds and ditches where conditions may be more favourable. When conditions improve the cyst bursts and the amoeba emerges to resume normal life. Sometimes the cyst bursts to liberate not one amoeba but many, as a result of the original organism dividing several times when enclosed in the cyst. This is known as *multiple fission* and the small amoebae are referred to as *spores*.

Other Forms of Amoeba

So far we have described the structure and physiology of the species of amoeba called *Amoeba proteus*. There are other organisms sufficiently similar to *Amoeba proteus* to form part of the genus *Amoeba*, but with small differences which justify different species names. One such example is *A. limax*, which differs from *Amoeba proteus* by forming only one pseudopodium at a time.

There are also parasitic forms of amoeba, usually called *Entamoeba*, which have no contractile vacuoles. One species, *E. histolytica*, causes amoebic dysentery in human beings. It lives in our intestines where it digests and assimilates the cells lining them. This parasite often gets into us when we drink infected water. To be sure of clean water, all drinking water should be boiled in order to kill the germs, unless it is known that the water has been purified by public health authorities.

Euglena

When cultures of *Amoeba* are not obtainable, it is equally useful to study *Euglena*, which is also a Protozoan and which is readily obtained from pools and ditches contaminated with urine and faeces, or stagnant water containing nitrogenous organic matter. This organism is a little more advanced than *Amoeba* since it has a few more specialized organs for carrying out the functions of life. For example, the genus *Euglena* consists of organisms which bear a long, slender filament called a *flagellum*, which is used in movement. Here we shall describe the species *Euglena viridis*, which is noted for containing the green chlorophyll normally found in plants. In this way *Euglena viridis* is virtually intermediate in its make-up and physiology between plants and animals.

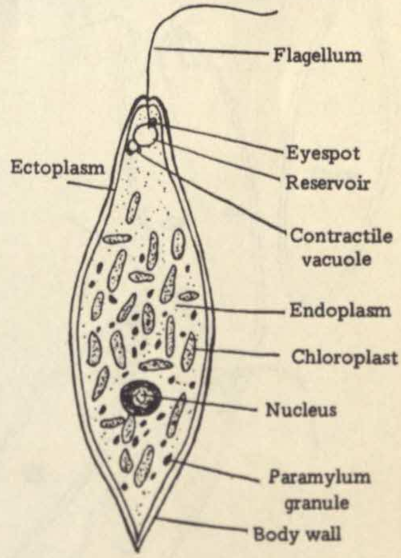


Fig. 4.5. Structure of *Euglena viridis*

Structure. (Fig. 4.5.) *Euglena viridis* is a free-living protozoan with a slender, elongated body about 0·1 millimetre long. The front of the body is blunt while the opposite end is pointed. Unlike *Amoeba*, *Euglena* has a constant shape, which is maintained by a thin flexible membrane called a *pellicle*. The protoplasm consists of a clear outer ectoplasm, and a granular inner endoplasm. At the front of the organism is the *gullet*, at the bottom of which arises the flagellum. At the base of the cell-gullet is a round structure, the *reservoir*, as well as a contractile vacuole, which help to remove unwanted fluids from the body. On one side of the reservoir is an *eyespot* which is sensitive to light. Inside the cytoplasm are structures called *chromatophores* which

Fig. 4.6. Euglenoid movement

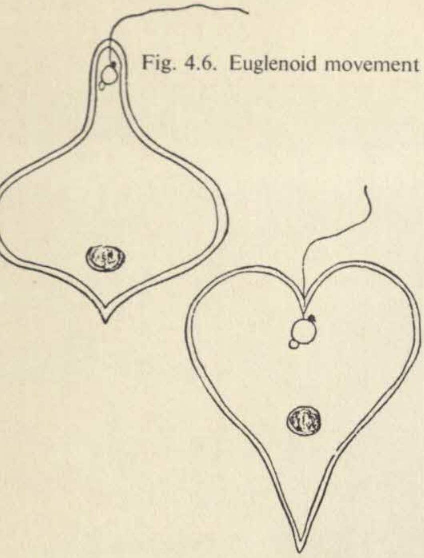
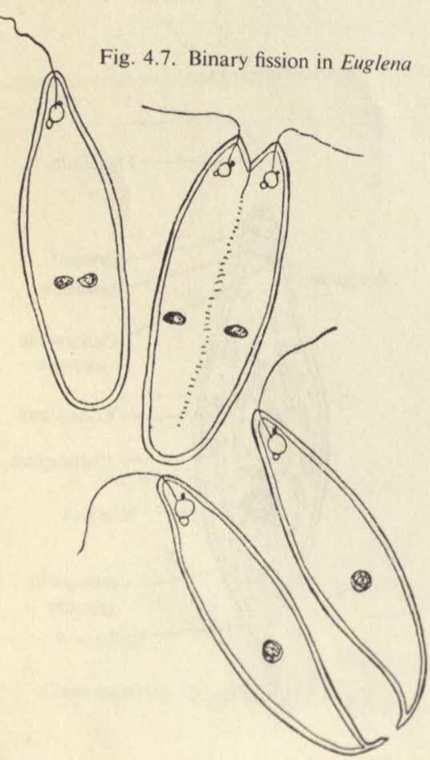


Fig. 4.7. Binary fission in *Euglena*



contain the chlorophyll. This is peculiar in an organism that is otherwise an animal. There are also some grains of carbohydrates. The nucleus is round and lies in the lower half of the body.

Movement. The flagellum is the main structure for movement. By beating it backwards the organism is drawn through the water. *Euglena* moves on a straight course while rotating on its own axis and in a spiral fashion. Apart from this mode of movement, *Euglena* at times also expands and contracts parts of its body with the aid of its flexible pellicle. This enables it to assume many peculiar shapes (Fig. 4.6). This sort of movement is so typical of *Euglena* that it is referred to as *euglenoid movement*, just as we found amoeboid movement typical of *Amoeba*.

Nutrition. Since *Euglena viridis* contains chlorophyll it has the holophytic mode of nutrition typical of plants. This means that food is synthesized within the body by photosynthesis. Apart from this, *Euglena* is also able to absorb some organic as well as inorganic materials dissolved in the water in which it lives. This is a saprophytic mode of nutrition.

Respiration. *Euglena* is able to use the oxygen dissolved in the water in which it lives. This oxygen is taken in through the whole body surface, and helps to break down some of the products of photosynthesis which are stored in the body. Carbon dioxide produced as a result of respiration is given out from the body into the surrounding water.

Excretion. Any waste products in the body are first collected into several minute contractile vacuoles. Later these empty into the larger reservoir. From here the waste is removed from the body through the cell-gullet and the cell-mouth.

Irritability. *Euglena* reacts to light of the right intensity by swimming towards it. In this it behaves like an ordinary green plant which grows towards light. But it tends to avoid direct sunlight. As in most other Protozoa, *Euglena* avoids unpleasant stimuli, and direct sunlight is evidently too strong for it.

Reproduction. Like *Amoeba*, *Euglena* normally multiplies by the asexual method called binary fission (Fig. 4.7). However, in this case the division of the whole organism and its nucleus takes place in a specific direction, since the animal has a definite shape. The nucleus first divides into two; this is followed by the division of the flagellum, the cell-gullet, the reservoir, and the eyespot, so that in the end the whole organism splits lengthwise from the front to the back.

In hot weather *Euglena* becomes inactive and secretes a cyst around itself as a temporary protective device. If conditions get worse, for instance, through drought or scarcity of food, *Euglena* may lose its flagellum, and form a cyst, inside which it divides into sixteen or thirty-two small euglenas.

In conclusion, we find that *Euglena* is more specialized than *Amoeba*. Its structure is more complicated, and it also separates its physiological processes to a greater extent.

Paramecium

Paramecium is an interesting organism to study because it shows a very high degree of organization and specialization for an acellular

organism. In this respect it is more advanced than *Amoeba* and *Euglena*. It belongs to a group of Protozoa characterized by the possession of numerous short hair-like structures called *cilia* by which the animal moves.

It is often found that *Paramecium* multiplies rapidly in infusions made by soaking hay in water, where it feeds on bacteria. We shall be describing the species *Paramecium caudatum*.

Structure. (Fig. 4.8.) *Paramecium* is simply described as slipper-shaped (with its blunt end in front) and is sometimes called the 'slipper animalcule'. The body is thus of a definite shape as in *Euglena* but it does not alter its shape as do *Amoeba* and *Euglena*. The cilia are set on a definite elastic membrane which covers the body and is called the *pellicle*. The pellicle, which is in reality part of the protoplasm and not a cell-wall, is strengthened by a number of fine rods called *trichocysts*. The latter are embedded in a narrow clear layer (ectoplasm) just below the pellicle.

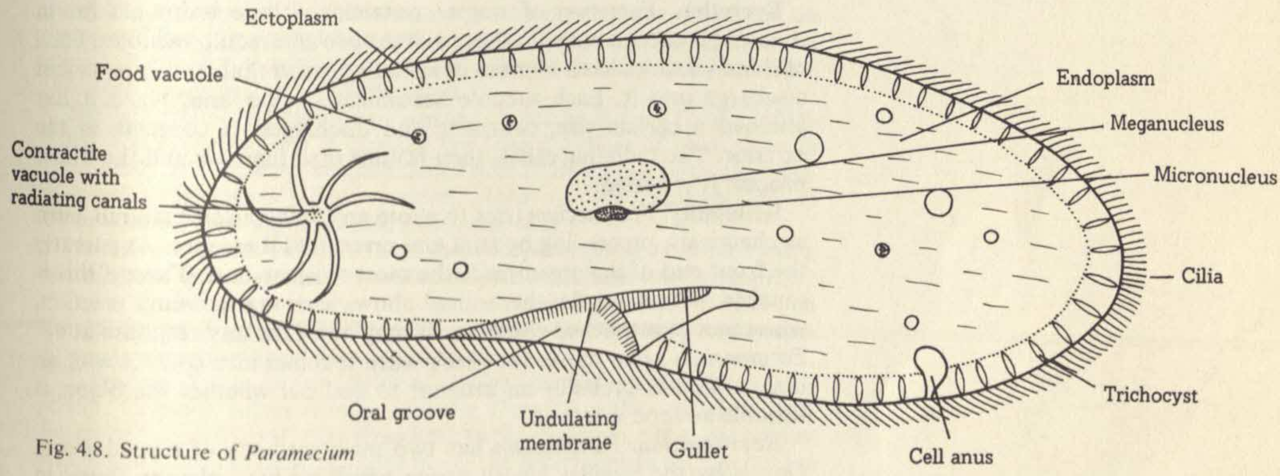


Fig. 4.8. Structure of *Paramecium*

Inside this is the more granular endoplasm. A shallow groove (*oral groove*) is found on one side of the organism; a small tubular gullet leads from this into the endoplasm.

There is a cell-anus just behind the gullet. In the endoplasm there are food-vacuoles and two contractile vacuoles, one at each end. *Paramecium* is characterized by the possession of two nuclei, a larger one (*meganucleus*) partly surrounding the smaller one (*micronucleus*).

Movement. *Paramecium* moves in the water with the aid of its cilia, which beat backwards to carry the animal forwards. While moving, *Paramecium* also rotates because the cilia beat in an oblique fashion. At the same time the cilia in the oral groove beat much more vigorously than on the rest of the body and this makes the organism swim along a spiral path. All this results in a specific course of travel. When *Paramecium* encounters either a solid object or an unfavourable chemical in the water, it avoids it by reversing the beat of the cilia. This enables it to move backwards a little, and before it moves forwards again it tries to find a safer direction by allowing samples of water ahead of it to pass through the oral groove so as to determine their nature.

Feeding. The food of *Paramecium* consists mainly of bacteria, small protozoans, and algae. The water containing these organisms is drawn into the gullet by movements of the cilia in the oral groove as well as by the undulating membrane. The food is collected in a watery vacuole situated at the end of the gullet. The vacuole then gradually enlarges and, after reaching a certain size, breaks off and becomes a food-vacuole which follows a definite route in the endoplasm until it reaches the posterior part. A new vacuole then begins to form to replace the first one, and the process starts again. The endoplasm secretes enzymes which help in the digestion of the food, and it also absorbs the digested food. Any indigestible residues leave the body through the anus.

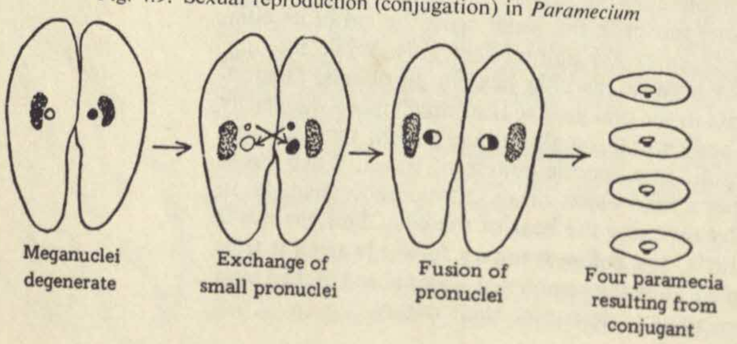
Respiration. *Paramecium* is not much more specialized than *Amoeba* with respect to its process of respiration. There are no special structures and the animal absorbs dissolved oxygen through the entire body surface from the surrounding water and similarly releases the resulting carbon dioxide by diffusion.

Excretion. Excretion of water containing a little ammonia (as in *Amoeba*) is carried out with the aid of the two contractile vacuoles. Each of these vacuoles has a number of *radiating canals* that converge on and discharge into it. Each vacuole accumulates water and, when it has attained a certain size, contracts and discharges its contents to the exterior. The radiating canals then resume their function and the whole process is repeated.

Irritability. *Paramecium* tries to avoid any unfavourable stimuli, such as chemicals, proceeding by trial and error until it escapes. Apparently the front end of the organism is the most sensitive part. Thus, if this is touched with a needle, the animal shows a strong avoiding reaction, whereas if it is touched elsewhere it may not show any response at all. *Paramecium* often moves forwards when it comes into contact with an object. This is probably an attempt to find out whether the object is suitable as food material.

Reproduction. *Paramecium* has two main methods of reproduction. One is by the familiar *binary fission* which we have already found in *Amoeba* and *Euglena*. Each of the two nuclei divides into two; one of the two halves of each nucleus moves towards one end of the organism. This is followed by a transverse division of the protoplasm just behind the gullet. When this is completed the two products are each found to have a contractile vacuole, but only one of them has a gullet. The one without a gullet later develops one. They grow to their full size and

Fig. 4.9. Sexual reproduction (conjugation) in *Paramecium*



divide again. *Paramecium* can divide about four times a day thus producing sixteen progeny from one individual.

The other mode of reproduction is sexual reproduction (Fig. 4.9). This is the first time we have come across a process like this in single-celled organisms. It is much more complicated process and involves two individuals coming together and exchanging parts of their nuclear material. The process is called *conjugation.* The end result of this process is the production of four individuals from the two original ones. The details are too complex for us at this stage of our studies.

SUGGESTED PRACTICAL WORK

1. *The Microscope.* A study of very tiny animals and plants is only possible with the aid of a microscope. This instrument has to be handled very carefully since it is easily damaged and is very expensive.

Ask your teacher to demonstrate the use of the microscope, and pay particular attention to the following parts: the eyepiece, the drawtube, the coarse and fine adjustments, high and low power objectives, the stage, and the mirror. Some microscopes have additional refinements such as iris diaphragm, sub-stage condenser, and coloured filters.

The first compound microscope was developed by Robert Hooke (1635–1703), and it enabled him to examine and record sections of plant stems in great detail. His drawings of small things were recorded in a book appropriately called *Micrographia* (*micro*—small, *graph*—to draw), and you should try to discover as much as possible about this work.

Little improvement was made to the microscope for the next hundred years, but by about 1880 the forerunner of the modern instrument was developed.

Today there exists a number of very complicated microscopes, and you should try to discover something about them—for example, the phase-contrast microscope and the electron microscope.

2. *Amoeba.* Try to find examples of *Amoeba* in standing water near your school. Carefully collect samples of water from the surface of mud, dead leaves, or pieces of wood. Take these back to the classroom, where the teacher will mount a drop of each on a slide under the microscope to see if you have got any amoebae. If so, he will set up a demonstration for everyone in the class to examine.

Notice particularly how *Amoeba* moves. After this the teacher will replace the water under the cover-slip with iodine solution. This will stain the nucleus and make it visible, although it will also kill the amoebae.

3. *Paramecium.* The following culture method is suggested for *Paramecium*:

Boil up some banana skins in a beaker of rain water and transfer the solution (now rich in organic substances), when cool, to a wide-mouthed jar containing a little pond-water. This jar should be left undisturbed on a shady window-sill and protected from strong sunlight for about a month. The top of the jar must be covered with a thin layer of muslin to keep out mosquitoes. The surface layer of scum must not be disturbed on any account since it helps to maintain acidic conditions in the culture. After a few weeks large numbers of another protozoan may appear, but these will be succeeded in due course by *Paramecium.*

CHAPTER FIVE

Hydra—A Many-celled Animal

THE study of *Amoeba*, *Euglena*, and *Paramecium* has shown us that all the life processes of a living organism can go on within the limits of what looks like a single cell. Such organisms are called *Protozoa*. We are now going a stage further, to study an organism made of many cells (or *multicellular*). Organisms of this structure are referred to as *Metazoa* (as opposed to *Protozoa*). The possession of many cells for the body suggests that different cells perform different kinds of work. A group of cells which performs a special function is called a *tissue*, and tissues may also be grouped to form *organs*, each of which performs an integrated function.

Hydra is one of the simplest multicellular animals and thus serves to illustrate at a low level the specialization of cells found in the Metazoa. In the tropics, *Hydra* is more commonly found in the West Indies. It occurs less frequently in Africa and Asia but can be found in stagnant or slow-moving fresh-water streams or ponds and has been called the fresh-water polyp. It adheres to plants or stones.

Structure. *Hydra* (Fig. 5.1) is a much bigger animal than the acellular ones so far described. It is about 20 millimetres long and can be seen under the hand-lens as a slender green object with several hair-like structures known as *tentacles* at one end. It attaches itself by the other end to stones, sticks, or water-plants. This end is closed to form a 'foot'. The body is cylindrical and tubular. The end of the animal bearing the tentacles has a small mouth-opening situated on top of a central cone or *hypostome*. At the side of the body the animal may bear *buds* which later become detached and function as new individuals. Other rounded projections, the *ovaries* or *testes*, are sometimes borne on the body. This is the first time in our studies that we have come across a group of cells functioning as sex-organs.

Fig. 5.1. External features of *Hydra*

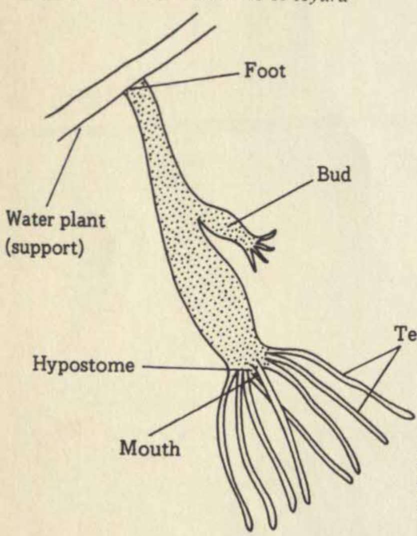
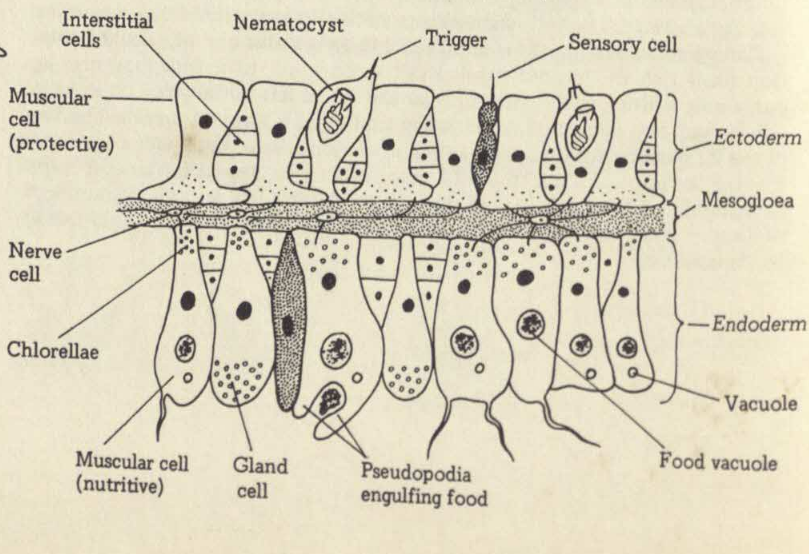


Fig. 5.2. Internal features of *Hydra*



Internally, the animal is made up of two layers of cells, both in the body and in the tentacles (Fig. 5.2). These are a thin outer layer called the *ectoderm*, which consists mainly of cubical cells, and a thicker, inner layer called the *endoderm* and made up of rather tall cells. Between these two layers is a thin strip of sticky jelly-like substance, without cells, called *mesoglea*. The ectoderm is essentially a protective and sensory layer; the endoderm, however, is digestive in function, while the mesoglea serves as a support for these two cell-layers.

The ectoderm is made up of a number of specialized cells such as:

(*a*) *muscle cells*, with extensions called *muscle-tails*, which can contract so that the body of the hydra becomes short and fat;

(*b*) *nerve cells*, with several branched processes, which join at their ends to form a *nerve-net* all over the body;

(*c*) *sense cells*, with small projections pointing outside, which are sensitive to touch and other stimuli.

(*d*) *interstitial cells*, which are found in the ectoderm all over the body and which can grow into any of the specialized cells of the ectoderm when replacements are necessary.

The endoderm cells are also further specialized into sense cells (as in the ectoderm), *secretory cells* (which secrete digestive enzymes into the body cavity, or *enteron*, to aid digestion of food), and *nutritive cells*. The latter cells have muscle-tails like the muscle cells of the ectoderm, but in this case the body of *Hydra* becomes narrower and longer when they contract.

It has already been mentioned that *Hydra viridis* looks green. This is due to the fact that in this species the contents of the nutritive cells include some unicellular green algae (plants) called *Chlorellae*. This is an example of *symbiosis*, which we have defined previously as an association of different organisms for their mutual benefit. In this case the plant is able to make use of the nitrogen waste products of the hydra, while the hydra uses the carbohydrates manufactured by the algae.

Movement. We have already mentioned one type of body movement in *Hydra* brought about by the muscle cells of the ectoderm (which contract the animal into a short, thick shape) and the nutritive cells of the endoderm (which contract to make the animal tall and thin) (Fig. 5.3). The main types of locomotion are gliding, walking and somersaulting. *Hydra* glides slowly along its support by means of an amoeboid movement of the pseudopodia-like structures on the cells of the foot.

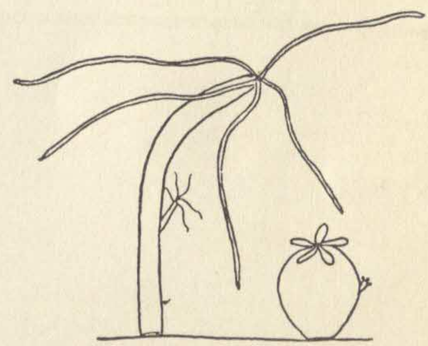
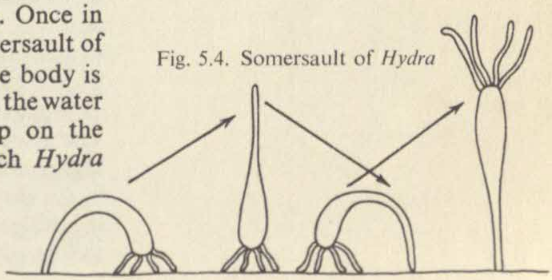


Fig. 5.3. Movements of *Hydra*

When performing the walking movement, *Hydra* bends its body over into a loop so that the tentacles touch the support at some distance away from the foot. The foot is then moved towards the tentacles. Once in this new position the animal raises its tentacles again. The somersault of *Hydra* (Fig. 5.4) starts like the walking movement. When the body is bent into a loop, the foot is released completely and is moved in the water to the other side of the tentacles, where it takes a new grip on the support. This somersault is the most rapid method by which *Hydra* moves.

Fig. 5.4. Somersault of *Hydra*



Feeding. The food of *Hydra* consists of small crustaceans such as water-fleas and insect larvae; occasionally *Hydra* is able to swallow food objects bigger than itself. When *Hydra* is hungry it stretches its body and tentacles; the latter are waved about and when they touch the prey certain stinging cells in the ectoderm of the tentacles (called *nematocysts*) are discharged into the prey to paralyse it. The tentacles then bend to pass the food towards the mouth, which opens to allow it to enter the upper part of the body cavity. Here the secretory cells discharge enzymes to act on the food and reduce some of it into a soluble, digestible form which is absorbed by some of the cells of the body cavity. This type of digestion, which takes place outside the cells of the body cavity, is typical of multicellular animals, and is referred to as *extra-cellular digestion.*

Hydra also displays a second type of digestion, which occurs within individual cells, very much like the digestion within the single cell of an acellular organism. Part of the incompletely digested food is taken in by nutritive cells in the body cavity which send out pseudopodia, as in *Amoeba*, to draw the food into vacuoles, and further digestion takes place here. This is called *intra-cellular digestion.* Any undigested food is then got rid of through the mouth. Thus the mouth in *Hydra* acts in addition as an 'anus'.

Respiration. *Hydra* does not seem to have advanced any further than the unicellular organisms with regard to respiration. The oxygen required for respiration is absorbed from the surrounding water by any of the cells of the body, and the carbon dioxide diffuses out in the same way.

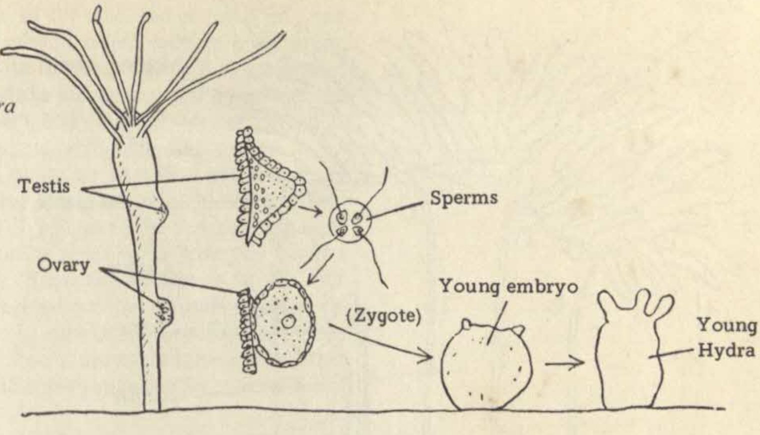
Excretion. Like respiration, the method of excretion resembles that in the Protozoa. No special organs are present for the purpose, and there is a general diffusion of nitrogenous waste substances from each cell.

Response to Stimuli. We have already pointed out that the various movements shown by *Hydra* are co-ordinated by impulses which pass through the nerve net. Generally, the state of the animal has an effect on its behaviour towards a stimulus; for example, when hungry, *Hydra* responds more actively than when it is satisfied. It often shows an avoiding reaction towards the touch of a needle, strong light, or an injurious chemical substance. Apart from responding to external stimuli, *Hydra* also reacts to internal factors, so that it may suddenly expand or contract its body without apparent cause.

Regeneration. *Hydra* has the ability to re-grow any lost parts of its body. This is called *regeneration.* Thus, if a tentacle is cut off, a new one later develops to replace it. Even when the animal is cut into pieces, each piece may be able to grow into a whole animal. If *Hydra* is split to some extent from the mouth downwards and the two parts are kept apart, a two-headed individual will be formed. Even when parts of two hydras are brought together, they can fuse to form a single animal. This is called *grafting.*

Reproduction. *Hydra* shows both sexual and asexual reproduction. The sexual mode of reproduction involves eggs and sperms and is a highly advanced and specialized method which we shall find more often in the more advanced animals. The asexual method is *budding.* The bud is a bulge in about the middle of the body, and is made up of different tissues like the main body. It grows into the various parts of the hydra,

Fig. 5.5. Sexual reproduction in *Hydra*



such as tentacles and a mouth. When fully grown into a miniature hydra it breaks off at the base and begins an independent life. Budding often takes place when there is plenty of food.

When, on the other hand, a dry period begins and food is generally scarce, *Hydra* begins to reproduce sexually (Fig. 5.5) by means of *gametes*—that is, sperms and ova, or egg-cells. These are produced in *sex-organs* (or *gonads*) which for sperms are the *testes* and for ova are the *ovaries*.

The gonads arise from interstitial cells of the ectoderm. The testes are produced higher up near the tentacles and the ovaries are much farther down. Although one animal may develop both sex-organs, they do not appear at the same time. The testes undergo a series of cell-divisions and produce many minute *sperms*, each bearing a tail, while the ovary, after going through similar cell-divisions, eventually produces a single large cell with much yolk, the *ovum*, which hangs suspended in the water. At this stage the testes release into the water the sperms, which swim to the ovary, where one of them will fertilize the ripe ovum. Soon after this the fertilized ovum secretes a thick wall and frees itself from the parent. This structure is the *zygote*, and after resting for some time at the bottom of the pond, a new hydra hatches from it when conditions are favourable.

Other Animals like Hydra

The study of *Hydra* has shown us some of the ways in which the Metazoa are more advanced than the Protozoa. As has been mentioned, *Hydra* is not easily obtainable in Africa and Asia, and it may be necessary to have a more common substitute in these areas; the *sea-anemone* (Fig. 5.6) is a suitable one. Not only does the sea-anemone belong to the same group of animals (the Coelenterates) as *Hydra*, but it is in fact a bigger animal and is therefore easier to deal with. Moreover, the structure is very much like that of *Hydra*.

In a way the sea-anemone is more advanced than *Hydra*. For example, if *Hydra* is cut into two equal parts longitudinally, the two halves will be very similar with respect to structures present. This is called *radial symmetry*. But in the case of the sea-anemone the arrangement of

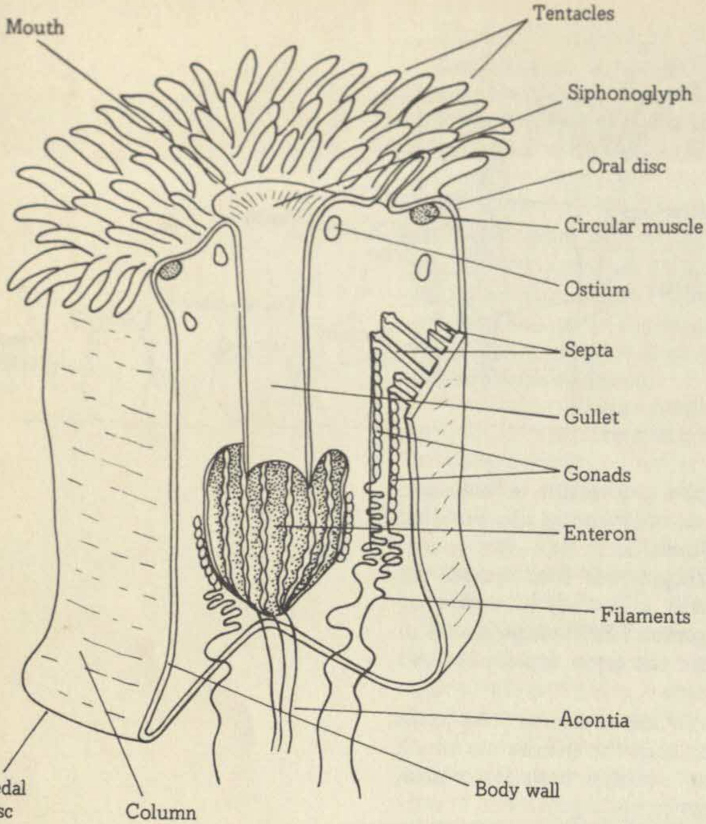


Fig. 5.6. Structure of sea-anemone

certain internal septa and of the gullet is such that there is only one direction in which the animal can be cut longitudinally in order to get two similar halves. This is called *bilateral symmetry*, and we shall find that it is a feature of nearly all the higher animals we shall later describe. Bilateral symmetry is regarded as more specialized than the radial symmetry of *Hydra*. This is why bilateral symmetry is regarded as an advanced character.

Another animal in the same group as *Hydra* and the sea-anemone is the jelly-fish.

SUGGESTED PRACTICAL WORK

1. Try to obtain *Hydra* in the following way: pour a quantity of pond-water or rainwater into a white sink and float on it some water-lily leaves for about a day. After this examine the sides of the sink for specimens of *Hydra*. *Hydra* can sometimes be seen with the naked eye, but a careful inspection is necessary.

2. (*a*) Use a hand-lens to examine the *Hydra* on the sides of the sink. The correct way to use a hand-lens is as follows: holding the lens close to your eye, move your head towards the specimen until the subject comes into focus (for clear focusing, the distance between lens and specimen may be as little as an inch).

(*b*) Detach a single hydra from the side of the sink and place it in some water on a cavity slide. When *Hydra* is disturbed it often reacts by contracting its body, so allow the animal to relax to its full length before examining it under the low power of the microscope. Make a drawing of it and label the mouth, tentacles (note their size and number), body, gonads—if present—and foot. Turn to the high power and examine one tentacle in detail.

3. If your school is situated in a coastal town, try to collect sea-anemones from the rocks at the sea-shore and bring them to the school for closer observation. Keep the water well aerated if you want the sea-anemones to survive for any length of time. Bring a quantity of sea-water with you and set up a small, temporary, marine aquarium. Keep the anemones in the salt water and be sure to keep the water well aerated and the animals well fed on meat fragments if you want the anemones to survive for any length of time. Remove any uneaten meat as it may decay and cause contamination. If your school is away from the sea, your teacher will show you preserved specimens of sea-anemones.

CHAPTER SIX

The Worm and the Snail

WHEN we use the word 'worm' we may be referring to *flat-worms*, *round-worms*, or *segmented worms*. All these animals show many advances over *Hydra* and its relatives. One indication of their advancement is the well-developed bilateral symmetry of the body. The worms have a specialized front end or 'head' and a hind end. They also have right and left sides, a lower or ventral part, and a top or dorsal part.

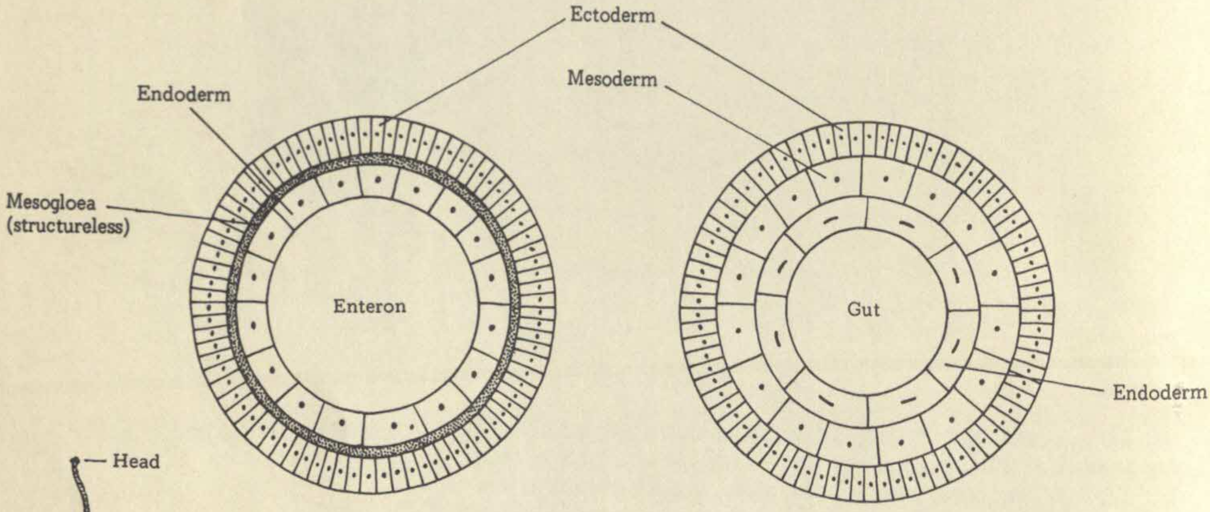


Fig. 6.1. Three layers of tissues in worms compared with two layers in *Hydra*

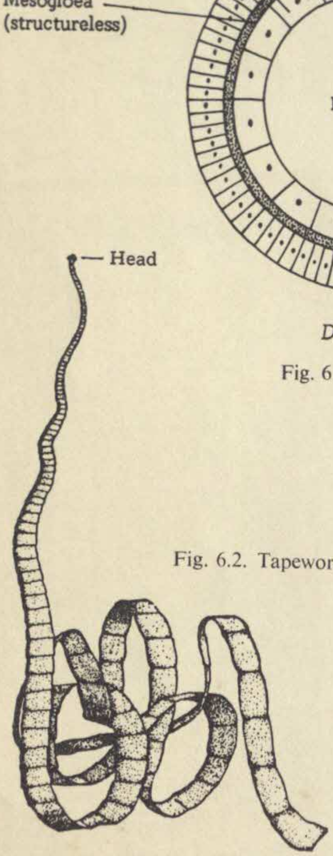


Fig. 6.2. Tapeworm

The other good reason for considering the worms more advanced than *Hydra* and similar lower animals is that in them we find for the first time a third layer of tissue between the ectoderm and endoderm. You may remember that in *Hydra* there was only a thin layer of thick jelly-like substance without any cells, called *mesoglea*, but in the worms and other higher animals a proper third layer made up of cells lies between the ectoderm and the endoderm (Fig. 6.1).

Now just a few words about the different types of worms. The flatworms are rather small and either free-living or parasitic. The parasitic ones are better known, since they cause certain diseases in man and domestic animals. A well-known one is the tapeworm (*Taenia*) (Fig. 6.2) which lives part of its life-cycle in the intestines of man and part in the muscles of the pig.

The Tapeworm

External Features. The tapeworm (here *Taenia solium*) is a parasite which commonly lives in the intestine of vertebrate animals. The body of the tapeworm is flattened like a tape but the head which is called the *scolex* is rather spherical and much smaller. The body is made up of a large number of distinct pieces each of which is called a *proglottis* (the plural is proglottides) and the total length of the tape is about 3 m long. These pieces are produced by budding from the neck region and so the proglottides get progressively larger and larger as they get away from the scolex. Between each proglottis and the next one is a transverse groove.

The scolex has no mouth but bears at its top a ring of hooks on a projection called the *rostellum*. Just below the rostellum are four *suckers*. It is by means of the rostellum and the suckers that the tapeworm is able to fasten itself to the lining of the intestine of its host. (See Fig. 6.3.) Each proglottis has its own reproductive organs, but it shares the single and common nervous and excretory system of the whole tapeworm.

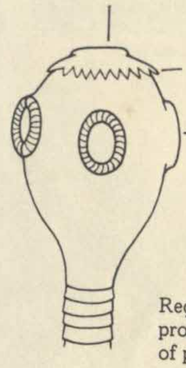


Fig. 6.3. Scolex of tapeworm

Internal Structure. Because, as a parasite, it depends on the host for its food, the tapeworm has no need for elaborate structures for the purpose. Thus it has no digestive system and is able to absorb through its cuticle already digested food of the host which surrounds it. Again the tapeworm has no special organs for respiration nor blood vessels. As far as muscles are concerned the tapeworm has only poorly developed longitudinal and circular muscles below the cuticle and these are enough for the feeble movements that it is capable of.

The excretory system consists only of a pair of excretory tubes which run the whole length of the body and open at the last proglottis. A cross tube, however, joins these long tubes in each proglottis. Also leading out of the main tubes, are smaller branches which reach all parts of the body. The end of each of these branches consists of a blindly-ending tubular cell with cilia in it, called the flame cell.

The nervous system is also not well developed. It is made up of a nerve ring in the head to which is connected two longitudinal nerve cords which lie close to the excretory tubes.

Reproduction. Each mature proglottis (that is in the middle of the worm) has a hermaphrodite set of reproductive organs, that is, both male and female organs.

The male reproductive organs consist of a number of small testes found at the anterior part of the proglottis. A single sperm duct with many fine tubes connect the testes together. The female reproductive organs are made up of a pair of ovaries, a uterus, a yolk gland, a shell gland. An oviduct with a system of tubes connect these together and leads through the vaginal tube to the exterior. (See Fig. 6.4.)

The lower part of the vaginal tube is slightly swollen into a sperm sac in which stored sperms fertilize the eggs. The fertilized eggs receive yolk from the yolk gland and a shell is secreted by the shell gland to cover them. All the reproductive organs, except the uterus then begin to degenerate, so that a ripe proglottis shows only the enlarged uterus containing the embryos.

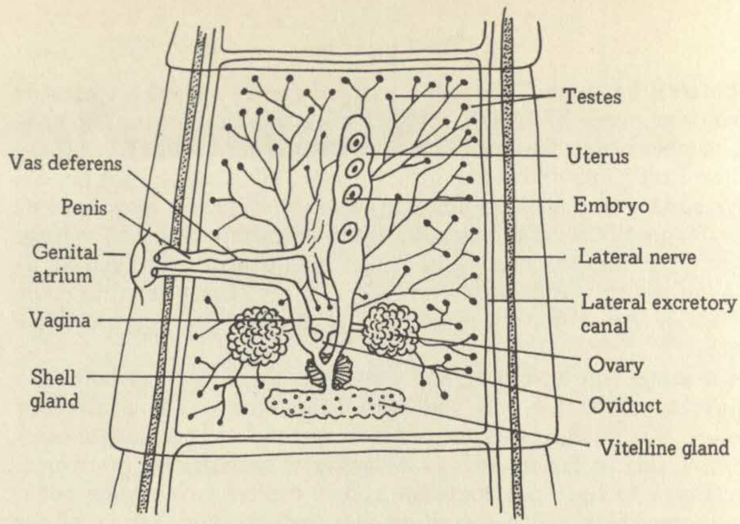


Fig. 6.4. Structure of proglottis of tapeworm

The ripe proglottides break away at the end segments of the worm and are discharged to the exterior along with the faeces of the *primary host* which in this case is man. When the embryos are eaten by the *secondary host*, which is the pig, the embryos begin to develop further. First the protective shell is dissolved by the digestive juices of the pig to release the embryo proper. The latter bears hooks with which it bores its way through the wall of the pig's intestine into its blood stream and finally encysts in its muscle tissues. Here the embryo grows into a bladder which is tucked inside at one point into a proscolex. This has the appearance of the tapeworm head turned inside out, and this stage is known as the bladderworm (Fig. 6.5).

Fig. 6.5. Bladderworm stage of tapeworm

The bladderworm gets into man when he eats uncooked or partially cooked pork. It travels into the intestine, where the digestive juices dissolve the bladder, and the proscolex is orientated into the scolex. The scolex is attached to the intestinal wall by means of the hooks and suckers, and begins to grow into a tapeworm by producing proglottides.

Economic Important. The tapeworm sucks the blood of the infected person from which it obtains its food. The infected person grows thin and often feels hungry. It is in order to prevent tapeworm infection that meat is inspected by the medical health staff.

It is thus advisable to cook pork adequately. It is also necessary to ensure, by the use of latrines that are sanitarily adequate, that human faeces do not contaminate the food of pigs.

Round-worms are long and pointed and are often found free in the soil or in water, although some are parasitic on plants (such as *eel-worms*) or in animals, including human beings. For example, the *hook-worm* and the *filaria worm* cause ill-health in many tropical countries.

Finally, the segmented worms are popularly typified by the *earth-worm*. We shall now discuss the earthworm in greater detail.

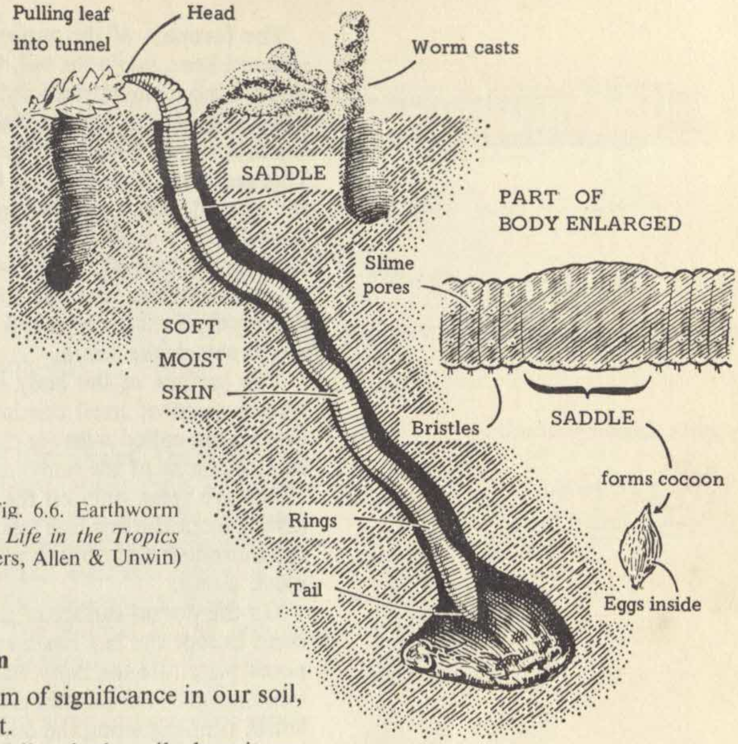


Fig. 6.6. Earthworm
(reproduced from *Animal Life in the Tropics*
by E. M. P. Walters, Allen & Unwin)

The Earthworm

The earthworm is an interesting organism of significance in our soil, and it is worth learning something about it.

Natural History. The earthworm (Fig. 6.6) lives in the soil where it can obtain moisture and decaying vegetation for its food. Thus, in the tropics large numbers can be found in the open savannahs beneath the tall grasses and in the forests in decaying tree-stumps. Indeed, in most soils there may be as many as fifty thousand earthworms per acre. However, they avoid the heaviest clayey, sandy, and acid soils. At night they crawl on the surface of the damp soil in search of food, but during the day they usually live underground.

It is also common to find the main part of the body of the earthworm in its burrow while its head is above ground. In this way it can search for food and at the same time be able to escape quickly from danger. The burrow is well prepared, with a layer of fine soil cemented inside by means of a secretion from the skin of the worm. As the worm pushes its way through the soil preparing the tunnel it eats its way along. Before soil is swallowed the worm secretes juices containing enzymes on to it. The soil first enters the gizzard where it is ground up and then passes to the intestine where digestion is completed. The worm excretes powdered soil in the form of *worm-casts* and these can be found heaped at the entrance of the burrow. They consist mainly of soil particles.

External Features. The earthworm has a very elongated body divided into a large number of rings or segments. The body is roughly cylindrical, especially the forepart, while the greater part of the remainder is slightly flattened. In tropical countries earthworms have been found measuring up to a foot or more in length, although generally they are smaller than those found in temperate climates.

The forepart of the earthworm tapers to a point and the mouth is situated here, while the tail, which is not so pointed, contains the anus. There is no clear external indication of a head. The upper surface of the body is darker in colour than the lower and the whole surface of the worm is rather moist, due to a secretion from certain glands in the body. This secretion, found on the thin layer of cuticle enveloping the body of the animal, has a number of useful functions. We have already mentioned that it helps to cement together the fine particles of soil lining the worm's burrow. Its other uses include that of a lubricant when the worm is moving through the soil, keeping the skin moist enough to make respiration easy, and killing harmful bacteria and fungi which might attack the worm.

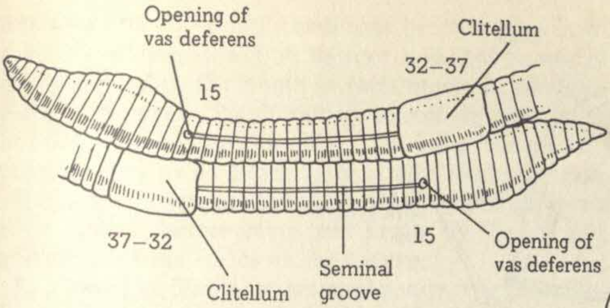
The surface of the body is not as smooth as it appears, due to an arrangement of small bristles which give it a certain roughness. These bristles are called *setae* (or chaetae) and four pairs of them project from each segment of the body, arranged in two double rows on each side. There are setae only on the lower half of each segment and they are absent from the first and last segments. The setae grip the ground while the muscular body of the worm lengthens and shortens, enabling it to move along.

On the dorsal surface of the body, after the ninth segment, each segment except the last has a small hole known as the *dorsal pore*. These pores penetrate the body wall to the inner tissues, opening on the outside into grooves between the segments. It is just possible to see a blood-vessel running along the dorsal surface of the body.

About one-quarter of the length of the body away from the mouth, some segments are thickened and fused together into a pad called the *clitellum*. A count of the number of segments from the mouth to the clitellum will show that the clitellum stretches from segment number thirty-two to thirty-five or thirty-six, so that five or six segments are involved in its formation. The clitellum has many glands and during reproduction plays an important part by secreting the *cocoon*, a container in which the eggs are laid by the worm. It is not easy to see any other openings of the various internal organs except those of the male reproductive organ, the testes. These can be found as slits on the lower side of segment number fifteen. The earthworm is a hermaphrodite, like *Hydra*, since it has both male and female sex-organs.

Reproduction. The earthworm has no asexual means of reproduction. It is a hermaphrodite, and its mode of reproduction is entirely sexual with cross-fertilization. Reproduction starts with a set of processes aimed at exchanging spermatozoa between two animals so that the eggs in each animal are later fertilized by the spermatozoa received from the partner. This is done by a process called *copulation* (Fig. 6.7). In this, two animals pair at night so that the head of one is close to the tail of the other. They lie on their sides with their lower surfaces in contact. The whole process is rather complicated and will not be fully described here. After a mucous envelope has been secreted to bind the two copulants together, seminal fluid is exchanged and stored in the opposite worm. When this has taken place the two worms separate.

A *slime-tube* is then formed to cover the body from segment number six to the end of the clitellum, and shortly after this the clitellum



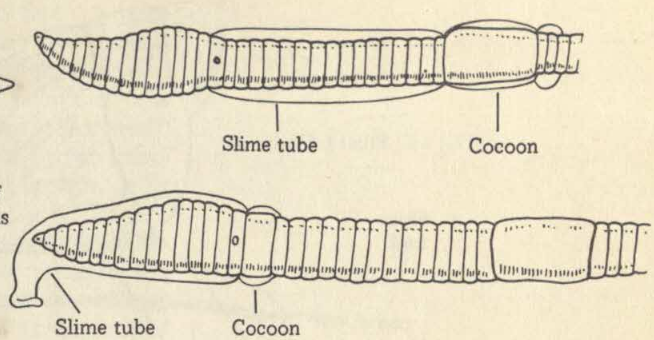
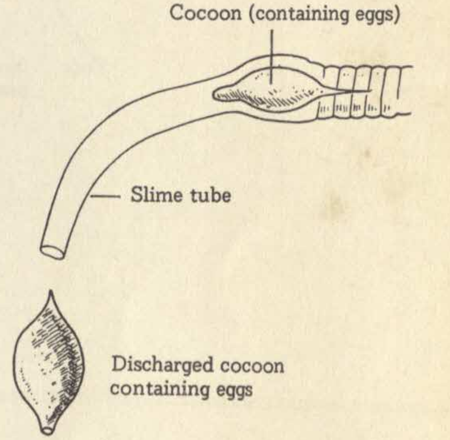


Fig. 6.7. Stages in sexual reproduction of earthworm



secretes the *cocoons* into which the eggs are later placed. These cocoons are formed at intervals and, as each is formed, about eight to sixteen eggs pass into it. The cocoon then moves away from the clitellum towards the head of the worm. As it passes over segment numbers nine and ten, seminal fluid is discharged into it and later this fertilizes the eggs after the cocoon has been deposited. The cocoons are small ovoid objects, often found lying under stones. The embryo in the cocoon develops into the young earthworm, which is very like the parents.

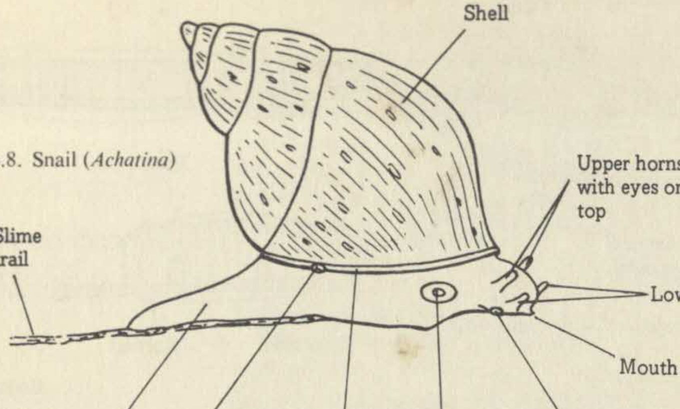
We may mention here that the earthworm, like *Hydra*, has the capacity to regenerate lost parts. Thus, if a worm is cut in two, each piece eventually replaces the lost part and becomes a complete worm.

Economic Importance. By its various activities in the soil, the earthworm contributes in no small measure to the betterment of the soil and the healthy growth of crops. It has been said that the earthworm is a better cultivator than any machine invented by man. First, by burrowing in search of food, the worm loosens the soil particles and forms countless channels. Not only does air readily enter through these channels, but rainwater also finds a quick exit from the base of the roots, enabling plants to grow more easily. Secondly, fresh soil is brought near the surface in the form of the fine particles or worm casts, together with inorganic matter which enriches the soil for plant growth. Finally, leaves and other vegetable matter which have accumulated in the burrows of earthworms and are not consumed later decay and add their humus to the layer of soil available for plant growth. In these ways, earthworms increase the fertility and productivity of soil for agriculture.

The Snail

The snail can be much bigger than the earthworm, and has a more complex body structure. It belongs to a group of animals called the *Molluscs*, and its body is soft but not segmented like that of the earthworm. Although the common snail has a protective shell, there are other animals in this group which have no such shell. The body tissues consist of three cell-layers like those of the earthworm, and the body also shows bilateral symmetry. The body is usually rather short and has a head region. There is also a muscular foot which is modified for movement.

Fig. 6.8. Snail (*Achatina*)



Molluscs show advancement in having a well-developed digestive tract, a circulatory system, kidneys for excretion, and a nervous system. We shall not be very concerned here with the internal structure of the snail since this is much too complicated for our present purposes, but will describe only the external features. As an example we shall describe the large African snail (*Achatina*), whose features broadly correspond to those of other snails.

External Features. The common snail or *Achatina* (Fig. 6.8) is found in damp places. It has a striped yellow and brown shell which may grow to a volume of about 300 cc. Most of the body of the snail is hidden in the shell when the animal is at rest, but when it begins to move, the head and the *foot* come out. The head, which is fleshy, bears two pairs of *tentacles* or *horns* which can either be thrust out or withdrawn into the body; it has also a pair of eyes, borne on long hollow stalks or *horns*, and a mouth. The foot is a mass of muscular tissue under the shell. The latter is made of calcium carbonate secreted by special glands at the boundary, or *collar*, between the shell and the foot. The mouth has a pair of jaws, the bottom lip of which is split into two. Inside the mouth is a rasp-like tongue bearing many spikes. Since there are no teeth, these spikes are used in grinding leaves by rubbing them against the horny roof of the mouth. There is a mucous covering over all the fleshy parts of the body and this may be exposed at one time or the other, so that mucus is secreted by slime-glands to keep the fleshy parts moist.

To the right of the mouth and farther up the head is the opening of the reproductive organs called the *genital pore*. A large breathing opening, or *respiratory pore*, and a small anus are also present in the soft mantle margin at the edge of the shell. The respiratory pore admits air into the breathing chamber.

Natural History. Apart from the water-snails, most common snails are active at night; during the day they normally hide in dark, damp situations beneath objects, in crevices, or in burrows. When the weather is dry they reduce loss of water from the body by secreting slime and mucus which hardens to seal the soft parts of the body inside the shell.

In this way they rest until conditions become more favourable. A snail moves by gliding slowly on its foot and, before this is done, a large slime-gland below the mouth secretes mucus or slime on to the ground to ease movement. By alternately stretching and shortening the foot, the body is moved over the slime, leaving a 'slime-trail' behind it. The return journey to its hiding place is also made along this 'slime-trail'.

Snails feed on green vegetation which is first moistened by the secretion of saliva, before being held firmly by the jaw and broken up by movements of the spikes on the tongue.

Reproduction. Snails are hermaphrodite, but generally cross-fertilization takes place as in the earthworm. Here, too, the procedure adopted for the exchange of spermatozoa between two snails is rather specialized. It begins with a mating performance in which a 'dart' is discharged from each of the two snails into the body of the other. Then the penis of each snail is inserted into the vagina of the other for the exchange of spermatozoa. After this, the two animals separate. Later, each of them lays eggs which are covered by round hard shells. These shells are about a quarter of an inch in diameter and are deposited in damp places or burrows. They hatch into minute snails, each with its own shell. The young snails are colourless at first but later darken to the adult colour.

Economic Importance. Snails do severe damage to crops and garden plants and even to trees in areas where they exist in large numbers.

Water snails carry bilharziasis, a weakening disease, transmitted to humans through the water the snails live in.

SUGGESTED PRACTICAL WORK

1. (*a*) *Tapeworm.* The teacher should contact a butcher for pork infected with tape-worm bladders. The class should examine a complete tape-worm and note the head (*scolex*), bearing suckers, and the chain of separate portions (called *proglottides*) which make up the body.

(*b*) *Liver Fluke.* It is sometimes possible to obtain specimens of this parasitic flat-worm from the local health authorities. The adult flukes inhabit the bile-ducts of infected mammalian liver.

2. *Earthworm.* (*a*) Collect some earthworms from damp soil and take them to the laboratory. Examine them, paying particular attention to the segments, the mouth, the clitellum, and the anus. The setae are better noticed if you draw the worm through your fingers.

Note. The local species may differ in a few respects from the general description given above. Therefore, count carefully, with the aid of the teacher, to find out the segments on which the various apertures and organs are situated.

(*b*) Put the earthworm on a fairly rough surface and note the movements it makes. How does it progress? Is its locomotion like that of a snake or not? Does the animal have a head end and a tail end? Can earthworms move forwards and backwards?

Place an earthworm on a piece of dry brown paper and listen very carefully as the worm begins to move. What do you hear, and how can you explain the sound?

(*c*) It is possible to make further observations on the habits of the earthworm by constructing a 'wormery'. The most effective form of 'wormery' consists of two sheets of glass slotted into a narrow wooden frame. A 'wormery' 25 cm × 30 cm × 1 cm will support two or three medium-sized earthworms. In setting up this apparatus try to build up layers of different-coloured soils. It is best to moisten each soil constituent before it is placed in the wormery. Be sure that each layer is firm and level before adding the next layer. Try to alternate fairly thick layers of farm soil with thin layers of sand, clay, chalk, and so on. At the very top, add dead leaves and other kinds of organic material, and take careful note of the things taken down by the worms. Try to keep the soil and humus damp without letting it become water-logged, and cover the glass sides with an easily removable brown paper sheet to exclude light.

Make periodic observations of the wormery and note the amount of mixing of the various soil layers as well as the shapes of the actual burrows.

Best results will be obtained if the wormeries are kept in a cool and shady place. (*Note:* Earthworms are nocturnal creatures—that is, they are usually active at night but not in warm, bright conditions.)

The most satisfactory way to obtain earthworms for your wormery is to search for them at night, with the aid of a torch.

3. *The Snail.* Obtain a snail from the market and examine it thoroughly; make a detailed description of its external features, following the account given in the text.

Place the snail on a sheet of clean glass and observe its movement from beneath. How can it glide along so easily?

With the aid of a hand-lens (see practical work suggestion 2(*a*) at the end of Chapter Four), try to discover the exact way in which the stalked eyes of the snail are protruded (pushed out) and retracted (drawn in). Make a series of diagrams to illustrate this movement of the eye-stalks.

Can you find the mouth of the snail? What kind of food does the snail take, and how does it treat its food before taking it into its body?

CHAPTER SEVEN

Prawns, Centipedes, and Spiders

PRAWNS, centipedes, and spiders belong to a large group of animals called the *Arthropoda*. In the same group are the insects, which, in fact, form a major part of the group. Other animals such as crabs, millipedes, and scorpions, which are well known to us in our daily life in the tropics, are also arthropods.

External Features. All these animals have similarities which are worth examining. In the first place, the body is covered externally by a protective skeleton. This skeleton is a cuticle formed from a horny substance called *chitin*. The covering is usually thick, but is flexible at intervals on the body and on the limbs where joints are provided to allow movement; it also provides the support to which the muscles of the body are attached. The provision of joints on the limbs is by itself an important feature of this group of animals.

In one way these animals appear to be similar to the earthworm; this is the division of the body into segments as well as the possession of bilateral symmetry. But it is possible to distinguish between them because, while the earthworm has as many as 150 segments, the Arthropoda are much shorter with only about twenty segments, some of which are often fused together. In the Arthropoda the jointed limbs occur in pairs on the segments which bear them, and at least one pair of these limbs is adapted to form jaws.

These few external characteristics should make it possible to identify any member of the Arthropoda. There are a number of internal characteristics too, but we cannot easily study them at this stage.

There are four major sub-groups making up this large group of Arthropoda. These are: the *Crustacea*, which include the crabs, prawns or lobsters, and barnacles; the *Myriapoda*, among which are the centipedes and millipedes; the *Arachnida*, which include the spiders, scorpions, and mites; and the *Insecta*, among which we may mention the cockroach, the grasshopper, the butterfly, the mosquito, the house-fly, and the honey-bee. As indicated above, insects form an important subgroup of the Arthropoda. We shall describe here the external features found in the other three sub-groups before we consider the insects in greater detail in the next chapters.

The Prawn

The Crustacea, to which prawns, lobsters, and crabs belong, have their own features which distinguish them from other sub-groups of the Arthropoda. Specific examples may be found in the list of practical work at the end of this chapter. In the first place, the body is divided into three regions, *head*, *thorax*, and *abdomen*. Some crustaceans have the front segments of the thorax fused with the head. Secondly, the first two segments of the head bear two pairs of long whip-like structures known as *feelers*. It is also typical to find that at least three limbs are

modified to act as jaws. The Crustacea typically live in water—that is to say, they are *aquatic*—and breathe by means of gills or through the general surface of the body where the exoskeleton is thin.

External Features. With these features in mind, a description of a prawn or lobster immediately shows us those features which it has in common with all Arthropoda and those it shares with other Crustacea. A prawn such as *Palaemon* (Fig. 7.1) has a thickened external skeleton (*exoskeleton*) covering the entire body. The body is divided into a number of segments, which are separated by soft joints, and to which muscles are attached. These muscles are in opposing pairs, so that when one muscle contracts the body is bent; when the other is contracted the body is straightened. The limbs are similarly arranged.

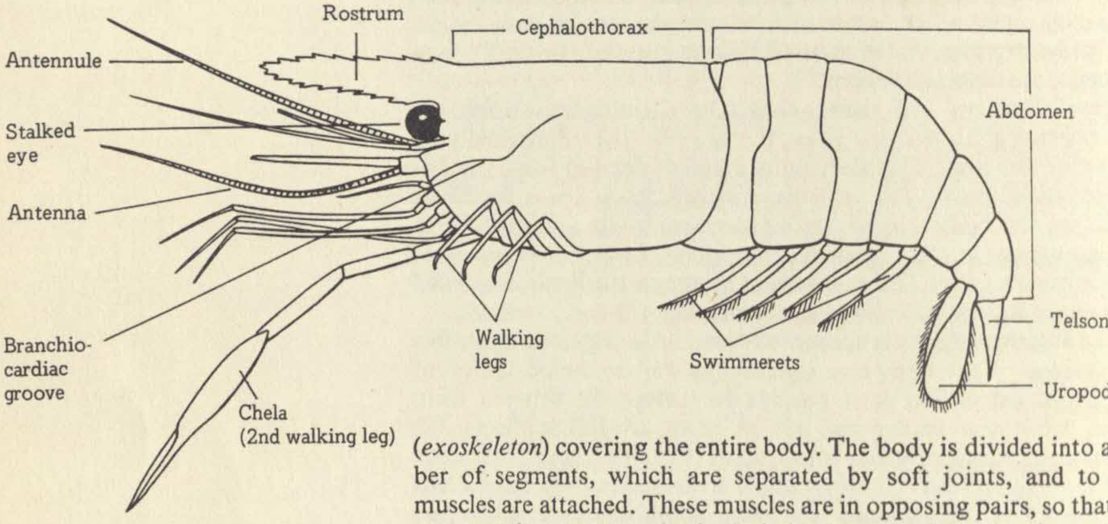


Fig. 7.1. Prawn (*Palaemon*)

When you look at the prawn you get the impression that the body is divided into only two parts. This is because the front part consists not of the head only, but of the head and the eight segments of the thorax fused together. This fused head and the thorax is known as a *cephalothorax*, and it is covered by the thick structure called the *carapace*. The remaining part of the animal is the abdomen. At the front of its head the prawn has a sharp beak or *rostrum*; behind this are the two pairs of long *antennae* or feelers, a pair of *stalked eyes*, and the *mouth*. Around the mouth are structures modified as *jaws* and *mouth-parts*. The cephalothorax also has five pairs of *jointed legs*. The two pairs of antennae have different functions. The smaller kind, called the *antennule*, has two branches and is sensitive to touch, smell, and balance. The longer kind, called the *antenna*, is also sensitive to touch.

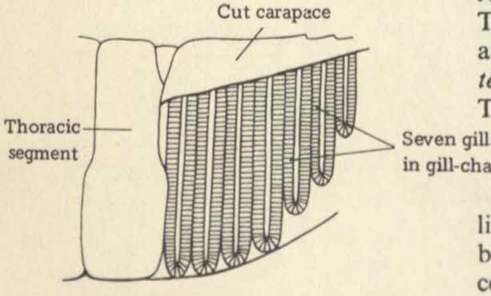


Fig. 7.2. Gills in the gill-chamber of prawn

The jaws and mouth-parts are made up of the next six pairs of modified limbs. The first ones are rather complex in form but farther back they begin to look more like true legs. We then come to the true legs on the cephalothorax. The first three pairs of these appear to be modified for picking up food particles in the water, while the last ones are more elongated and can be used for examining objects near the animal.

When we remove the carapace we find that this structure covers the *gills*, which are contained in a *gill-chamber* (Fig. 7.2). The gills are

feather-like structures and provide a large surface area for respiration by the absorption of oxygen from the water.

The abdomen of the prawn has five or six pairs of swimming feet, or *swimmerets*, and a piece of unsegmented end-joint called the *telson*, which looks like a 'tail' for the animal. Indeed, the swimmerets on the last abdominal segment just before the telson are large and form the *tail-fan*. A swimmeret has two branches, each of which is flattened into the shape of an oar and helps the animal in swimming. The tail-fan also has the special function of enabling the animal to dart backwards by suddenly bending its body.

Natural History. Because of the hard external covering, it is not possible for the prawn to grow readily. Before growth occurs, the skeleton is shed and a new one is formed to take its place. This process is repeated every time that growth takes place. The casting-off of the skeleton is called *moulting*. Growth thus occurs while the animal is soft. The prawn can replace lost parts of its body during moulting and growth.

Prawns live in shallow waters and feed largely on dead organic matter, while those living in fresh water also feed on green weeds. When the breeding season approaches the prawn swims into deeper water. In prawns, there are separate sexes, and the male produces spermatozoa which fertilize eggs from the female. After fertilization, the eggs may be carried between the swimmerets of the female or may be found loose. Later, the eggs hatch into small creatures not very different from the adult. They remain clinging to the bristles on the abdomen of the mother. After a few months they grow into the adult form.

The Centipede and the Millipede

The Myriapoda, to which the centipede and the millipede belong, are noted for their caterpillar-like form. The body is made up of a number of similar segments, each with one or two pairs of legs. Centipedes (Fig. 7.3) have one pair of legs on each segment while millipedes (Fig. 7.4) have two. They also have a distinct head which bears a pair of antennae, or feelers, and a pair of eyes. They differ from the Crustacea and are similar to the Insecta in that the respiratory system consists of air-tubes, or *tracheae*, which penetrate all parts of the body and open outside as holes, or *spiracles*, on the segments.

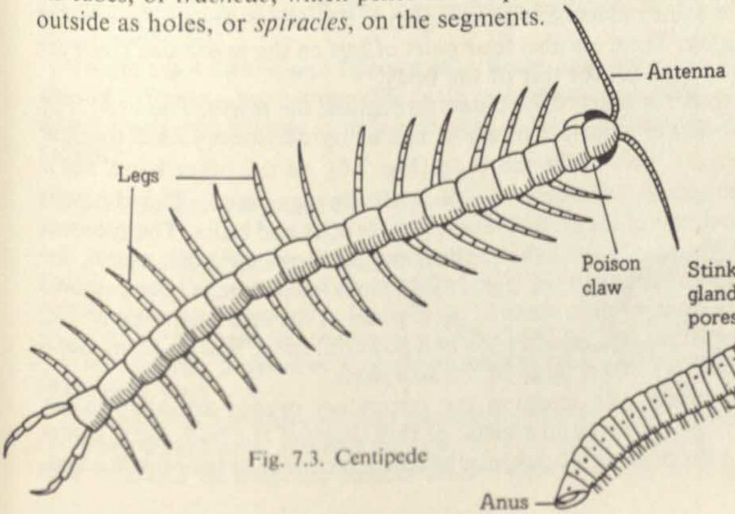


Fig. 7.3. Centipede

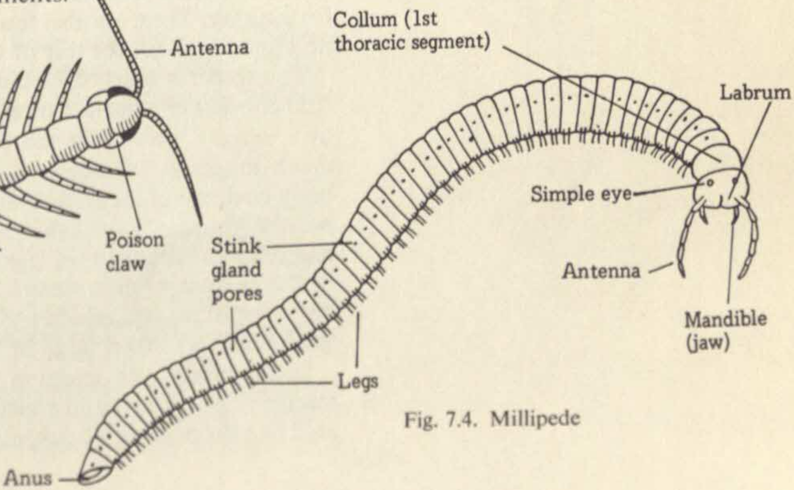


Fig. 7.4. Millipede

Centipedes and millipedes live mainly in tropical or warm countries. Centipedes hide by day under stones or logs and hunt at night. They are carnivorous and feed on insects and worms, thus helping to reduce their numbers; they can also harm us by their dangerous bite.

As indicated above, the body of the centipede consists of the head and a series of large segments which are flattened above and below. The head bears a pair of antennae, a pair of mandibles, and two pairs of maxillae. On the first segment of the body is a pair of *poison-claws* with ducts through which the animal ejects the poison to kill its prey. The prey is then chewed by the mandibles. Some tropical species are as long as seven inches and can inflict a very painful bite on man. However, the small, rather active 'house centipedes' feed on insects and are not harmful to man.

On each of the other segments of the body except the last two there is a pair of small walking legs. Centipedes have separate sexes and lay eggs. The females have hooks on the last segment for holding the eggs.

Millipedes live in damp, dark places on the forest floor or under rotting wood and tree trunks. They move rather slowly by using their numerous legs in a series of waves which progress from behind forwards. They can roll up into a spiral when disturbed.

The millipede is a vegetarian and may destroy seedlings and the roots of crops. Although its bite is not poisonous, it can protect itself from its enemies by secreting an irritating fluid from its 'stink-glands', which are situated on the side of the body.

The body of the millipede is cylindrical. Its segments are smaller and more numerous than those of the centipede. The millipede may be brightly coloured.

The Spider and the Scorpion

The Arachnida, of which the spider is a member, are characterized by the division of the body into two parts, called the *prosoma* and the *opisthosoma*, which correspond to the cephalothorax and abdomen in the Crustacea. There are no antennae or mandibles but there is usually a pair of eyes on the first segment. The prosoma bears a pair of grasping claws called *pedipalps*, and a pair of jaws called *chelicerae*, or *falces*, which in some orders bear poison-glands. The mouth-parts are adapted for sucking. There are also four pairs of legs on the prosoma. There are no appendages on the rest of the body.

The spider is widely distributed throughout the world. The body (Fig. 7.5) consists of a distinct prosoma and an opisthosoma joined together by a narrow 'waist'. The scorpion (Fig. 7.6), on the other hand, has a much longer opisthosoma which is clearly segmented. The chitinous body covering of the spider bears many bristles and hairs. The prosoma bears eight *simple eyes*, the mouth, the *chelicerae* or poison-jaws, the *pedipalps* and four pairs of legs. In scorpions the poison is not contained in the pedipalps but is secreted by a gland at the end of the body, *i.e.*, on the opisthosoma, which ends in a powerful *sting*. The grasping claws (pedipalpi) are rather large in the scorpions.

In the spider and scorpion the respiratory organs are adapted for taking in air directly and consist of thin sheets of the body wall, separated like the pages of a book, and situated in cavities in the opisthosoma.

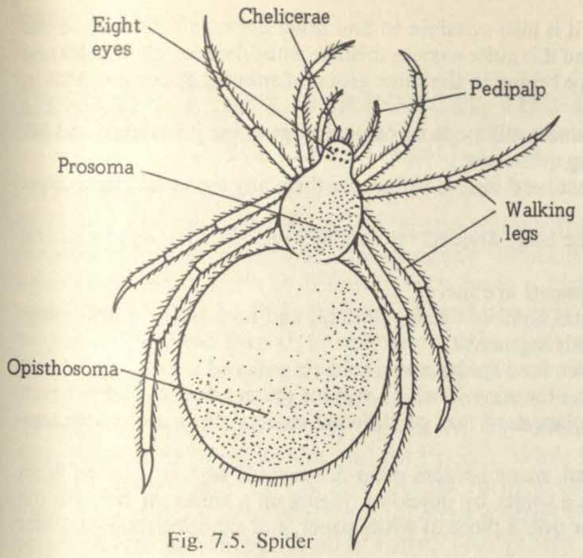


Fig. 7.5. Spider

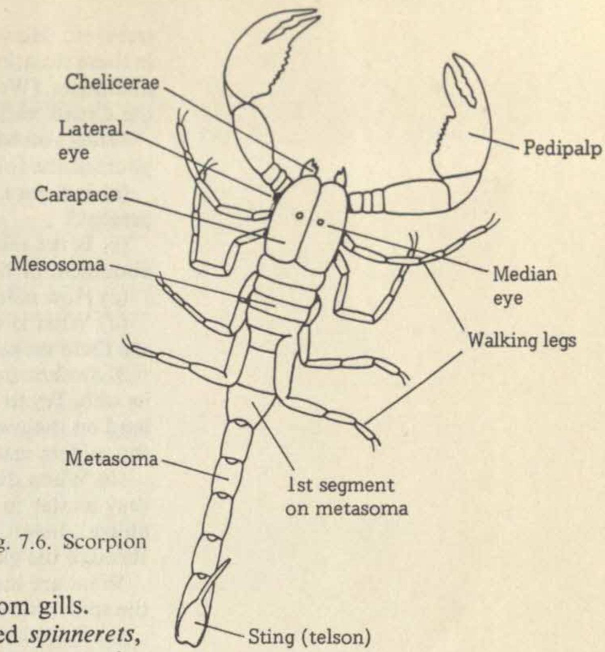


Fig. 7.6. Scorpion

They are called *lung-books* and appear to have evolved from gills.

The spider has three pairs of silk-spinning organs called *spinnerets*, which are situated on the lower surface of the opisthosoma near the end. Each of these opens through a hundred or more tiny tubes, and through these the silk is squeezed out. On reaching the air the silk hardens into a thread and may be used in spinning the web, in lining nests, in making egg-cases, or in binding up prey.

Spiders are carnivorous and feed on insects which they hunt or which they trap in their webs. The chelicerae in front of the mouth are used to seize the prey and then pour poison into it through their hollow tips. At the same time the pedipalps hold the prey whose body-juices are squeezed out for the spider to suck.

Growth takes place by moulting. Experiments have shown that spiders will regenerate maxillae, chelicerae, and spinnerets when these are damaged or broken off. The legs only regenerate to rather less than the original size.

Spiders are solitary, and tolerate each other only when it is time for mating. After mating between the male and female, the latter lays eggs which hatch into minute spiders and after a few months these are fully grown.

SUGGESTED PRACTICAL WORK

1. *Prawns*. Obtain some local prawns. (In West Africa species of *Palaemon* and *Atya* are the common forms.) Make a drawing of one side only of the animal, showing all the appendages. Remove the mouth-parts and note their different shapes. Remove the carapace to expose the gills. Draw the gills.

Where prawns, lobsters, or shrimps are not available, crabs can be studied in the same way.

2. *Millipedes*. Centipedes and millipedes belong to a group of animals called the 'many-legged ones' (Myriapoda), and it is quite an easy matter to find these creatures by searching beneath stones, underneath the bark of fallen

trees, etc. However, it is also possible to find other animals called wood-lice in these situations, and it is quite easy to mistake wood-lice for centipedes and millipedes. (Wood-lice belong to the same group of animals as prawns, that is, the Crustacea.)

When you have found a millipede or centipede, examine it in detail and ask yourself the following questions:

(*a*) Is there a distinct head visible? If so, are there any eyes and appendages present?

(*b*) Is the rest of the body divided into distinct regions such as thorax and abdomen, or not?

(*c*) How many segments are there?

(*d*) What is the total number of legs present, and how many pairs of legs are there on each body segment?

3. *Spiders.* (*a*) Search for a spider and a spider's web and watch how it spins its web. Try to observe the ways in which various spiders deal with flies which land on their webs; place dead flies on different spiders' webs and watch how the spiders react.

(*b*) When disturbed, many spiders drop downwards and so it is quite an easy matter to catch a spider by quickly bringing up a small jar beneath the animal. Invert the jar over a piece of white paper, and examine the live spider through the glass.

What are the two distinct regions of the body called? How many legs does the spider have, and are they all used in walking?

(*c*) Examine a dead spider with the aid of a hand-lens and answer these questions: (i) Where are the jaws? (ii) Are antennae present, or not? (iii) What shape are the pedipalps? (iv) How many and what kind of eyes does the spider have?

(*d*) In what ways are spiders and scorpions similar in body structure?

CHAPTER EIGHT

Insects: The Cockroach, the Locust, and the Mosquito

INSECTS are the most successful group among the Arthropoda and have considerable economic importance in our daily lives. The characteristics of insects are as follows: they have a jointed and chitinous exoskeleton. The body is segmented and the legs are jointed. Their bodies are divided into three regions: the head, thorax, and abdomen. The head bears a single pair of antennae, while on the thorax are three pairs of walking legs. The abdomen, however, has no walking legs. Respiration is carried out by means of air-tubes, or tracheae, and spiracles just as in millipedes and centipedes. While in some insects the young emerge from the egg in a similar form to that of the adult, in most insects the young ones pass through a series of distinct forms or stages before assuming the adult form. This process of transformation is called *metamorphosis.*

The Cockroach

We shall describe the cockroach to illustrate the essential characteristics of insects as outlined above. The cockroach is quite a convenient insect for this purpose since it is fairly large, easy to obtain, and has a rather simple structure when compared with a number of other types of insects. Many species of cockroach are found in the tropics, but a common one, called *Periplaneta americana,* is the one on which the present description will be based.

External Features. The cockroach (Fig. 8.1) is a dark brown insect with a flattened body, about four centimetres long. The body is divided into three regions: the head, the thorax, and the abdomen. The head and thorax are joined together by a narrow soft region known as the neck. The head is made up of six segments, although there is no sign of this externally; the thorax, however, consists of three distinct segments on which are borne the legs and the wings; some seven segments may be counted on the abdomen, but these are legless. The *head*

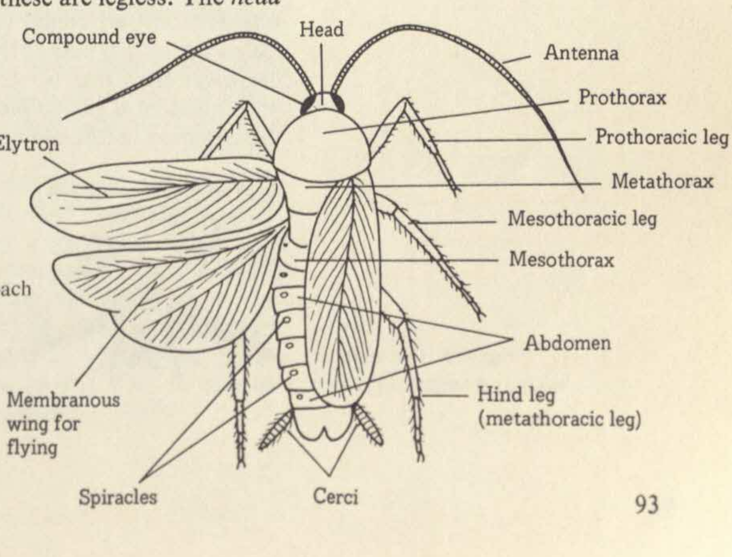


Fig. 8.1. External features of cockroach

is small and flattened from front to back and is held almost at right-angles to the axis of the body. At the side of the head are the two large black *compound eyes*. These are similar to those of crustaceans, but are not carried on stalks. The eyes are able to record quick movements. From just below each eye arises a long whip-like feeler, or antenna, made up of many joints. The antennae are sensitive to smell and touch and are always being moved, particularly when they receive stimuli.

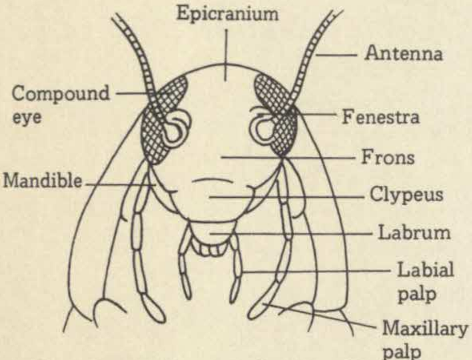


Fig. 8.2. Mouth-parts of cockroach

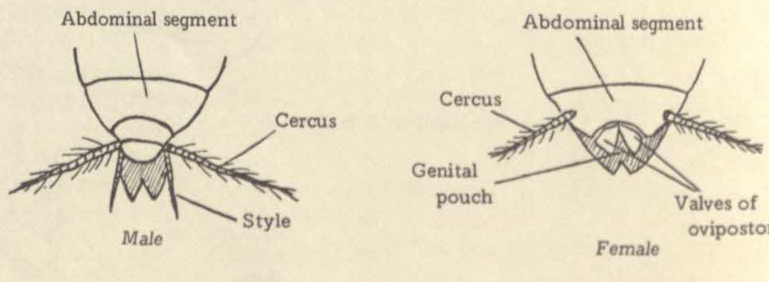
The mouth-parts (Fig. 8.2) of the cockroach have a simple structure. The insect is omnivorous—that is, it feeds on plant or animal material. The mouth, as in crustaceans, is wide and there is a pair of biting jaws or mandibles. These are so shaped as to be suitable for biting any kind of food. Just outside the mandibles are two jointed structures called maxillae, each with two blades, together with another jointed structure called the palp. There is a sort of lower lip called the *labium* below all these, and this has four blades and a palp on each side. The cockroach uses its mouth-parts for picking up pieces of food and carrying them to the mouth. Mouth-parts are adapted in different insects according to their mode of feeding, and we may remark here that, while the biting mandibles are large in the cockroach, they are small in the bee, and are virtually non-existent in the butterfly.

The thorax consists of three segments, each of which bears a pair of jointed walking legs with hooked claws. The second and third segments also each bear a pair of wings. The three segments are called *prothorax*, *mesothorax*, and *metathorax*. In the cockroach the prothorax is very large and its large covering protects the head by overhanging it. It also bears a breathing pore, or spiracle. The first pair of wings are thick and horny, while the second pair, which is folded like a fan under the first one when the insect is at rest, are membranous.

The abdomen consists of ten segments, each of which has a chitinous plate separated from the next one by a soft membrane. This acts as a joint and allows movement of the abdomen. At the side of each abdominal segment, except the last two, are pairs of breathing pores, or spiracles. The anus is on the last segment and on each side of it is one of a pair of structures called the *cerci*.

It is possible to distinguish between the male and the female cockroach by examination of the end region where structures associated with reproduction are found (Fig. 8.3). In the male these are paired rods called *styles* very near to the cerci. The abdomen of the male is generally narrower than that of the female. The female is distinguished by the possession of a *genital pouch*, below the seventh segment, which holds the egg-case before the eggs are laid in it.

Fig. 8.3. End-parts of male and female cockroach



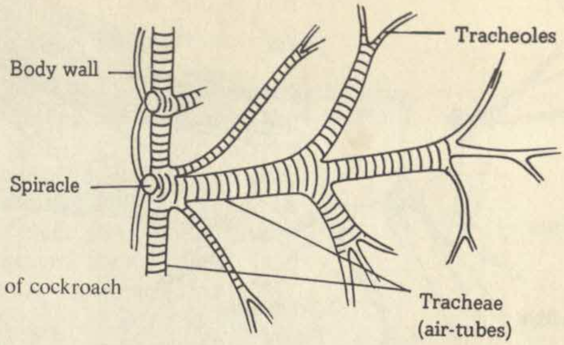


Fig. 8.4. Portion of the tracheal system of cockroach

Respiration. One characteristic feature of insects is their mode of respiration. We have already mentioned the presence of paired spiracles on eight segments of the abdomen and on two of the thorax. These breathing pores lead to a series of branched tubes called tracheae, or tracheal tubes, which are distributed throughout the body (Fig. 8.4). Oxygen reaches the cells of insects directly through this system without being carried by a blood-system. When the cockroach is dissected it is possible to see parts of the tracheal system looking like white lines.

Life-history. As mentioned, the sexes are separate in insects. The male produces sperm from the testes and eggs are produced in the ovaries of the female. The sperm is deposited in the oviduct to fertilize the eggs internally. After that, a shell is secreted round each egg which is then laid in the egg-case (Fig. 8.5) carried in the genital pouch of the female. The case is later hidden in a suitable place, usually a dark or obscure corner.

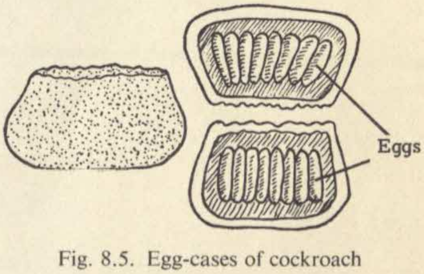


Fig. 8.5. Egg-cases of cockroach

The development of the young in the cockroach is said to show incomplete metamorphosis. (Other insects like the butterfly show complete metamorphosis.) This is because when the eggs hatch the young nymphs which emerge resemble the adult cockroach except that they are small, and have no wings or sexual organs. After a few months these structures are formed and a fully developed cockroach is produced.

Habits. As mentioned above, cockroaches avoid the light and keep to dark places. They are most active at night. It is possible that their rather large eyes are not of much use and it appears that they rely more on their long antennae which they move about to smell and to feel their way. It is common to find the cockroach cleaning its antennae by drawing them through its jaws. It also grooms its wings with its legs. When in danger or when frightened the cockroach secretes a substance with a very unpleasant smell.

Economic Importance. Cockroaches are well known in our houses as they often hide in dark places during the day and come out at night. They do not carry any particular disease, but they deposit their faeces on exposed food and in this way can spread germs to us. Their presence is an indication that the house is dirty. They are also our enemies since they may feed on our clothing and books which cost us money to replace. Cockroaches are easily transported long distances without our knowledge, along with boxes in which goods are packed. This is why the domesticated cockroach is found all over the world.

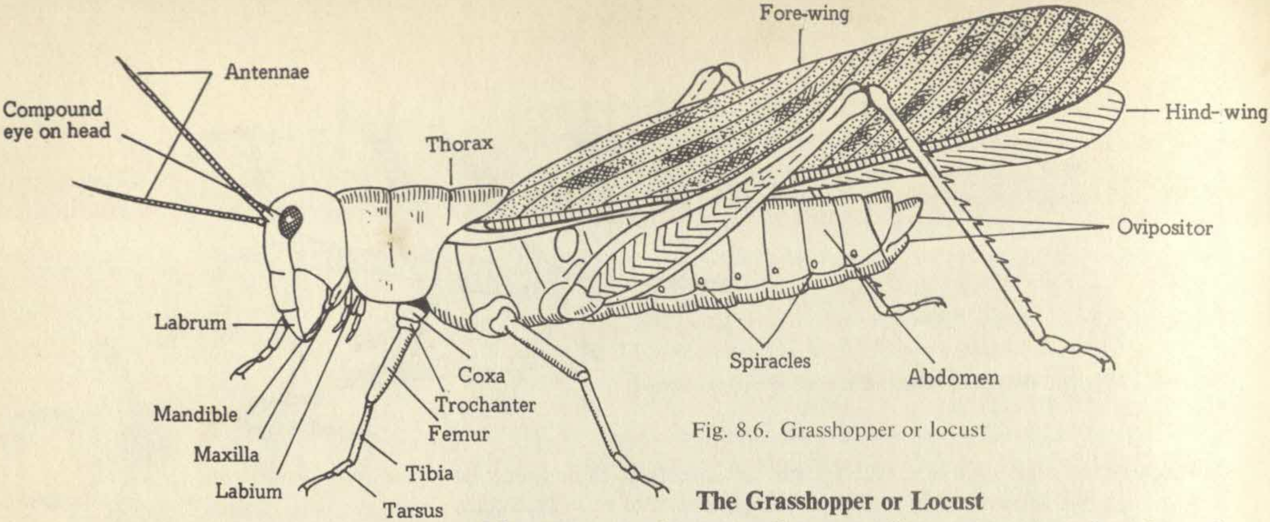


Fig. 8.6. Grasshopper or locust

The Grasshopper or Locust

The name grasshopper refers generally to the green, long-horned insect which lives by itself and only occasionally migrates, while the name locust is applied in the proper sense to the short-horned green or sandy-brown types that live together in large numbers and often migrate in swarms from place to place. There is little difference in their actual structure and the two types of insect are often described under one name.

The grasshopper (Fig. 8.6) is very similar to the cockroach in structure, and both mouth-parts are adapted for biting or chewing. The fore-wings are also modified into long, hardened structures. These overlap the hind-wings, which are membranous. They often bear a pair of long antennae on the head and a pair of jointed cerci on the abdomen. Finally, they undergo a gradual or incomplete metamorphosis from the nymph stage to the adult, as does the cockroach.

Mode of Life. Grasshoppers are found practically all over the world in open, sunny places such as grasslands, weed-patches, gardens, and farmlands, and in road-side vegetation. They feed on grasses and other leafy vegetation, especially those containing a large quantity of moisture. When food becomes scarce they migrate to new grounds, often very far away. During their migration they can destroy whole gardens or farms. Grasshoppers are able to feed on wood and clothing when vegetation is not obtainable.

The mode of movement or locomotion is characteristic in the grasshopper. Unlike the cockroach, the grasshopper has more powerful eyes suitable for the daylight, when it 'hops' actively with the aid of its long jumping legs. These often help it to escape from its enemies. But in fact the colour of the grasshopper gives it what is called 'protective coloration' against its enemies. The green forms often rest or feed on green bushes, whilst the sandy-brown forms rest on the ground. The enemies which feed on the adult grasshopper include frogs, reptiles, birds, and mammals, as well as some large insects.

Grasshoppers are noisy, but practically all the noise comes from the male insect, since the female has no organs for the purpose. The male has a row of tiny pegs on the inner surface of each of the long hind-legs. When it moves these against the hard veins of the first pair of wings the familiar chirping noise is produced. Other types of the insect make

noises by rubbing together the inner edges of the first pair of wings. This noise helps to bring the male and female insects together when the time comes for mating.

Life-history. During mating the male insect clings to the back of the female and transfers spermatozoa into the vagina. After fertilization the eggs are stored for some time by the female before they are laid. Adults die soon after the mating period. The female uses her *ovipositor* (a stiff, slightly curved tube on the abdomen) to make a hole in the ground in which about thirty eggs are deposited. The female also secretes a substance to form egg-cases to protect the eggs. Later the eggs hatch into the young or nymph stage. These nymphs are sometimes also called 'hoppers'. They have large heads and no wings, and grow rapidly as they feed actively on leafy vegetation. They moult six times before becoming fully grown adults.

Economic Importance. The grasshopper does damage to our crops and flowers. Particularly when grasshoppers migrate in large numbers, they can eat all types of crops and thus destroy whole farms. These migrations are watched so that steps can be taken to check them. One way of checking them is to spread in their way poisonous bait on which the nymphs and adults feed. Low-flying aeroplanes are often used in spraying poison over them. It is also possible to control them by ploughing up weed fields to expose their eggs. The problem of grasshopper or locust swarms threatens many parts of Africa, Asia, and America.

The Praying Mantis

The praying mantis (Fig. 8.7) is another common insect closely related to the grasshopper. It gets its name from the position in which it rests, which looks as if it was praying. The praying mantis has a rather long first segment of the thorax. It feeds on insects and, when waiting for its prey, stays quietly on its last two pairs of legs, waves its antennae around, and moves its head from side to side. It also draws its fore-legs beneath the head, and when its prey is within reach these are shot out to seize it.

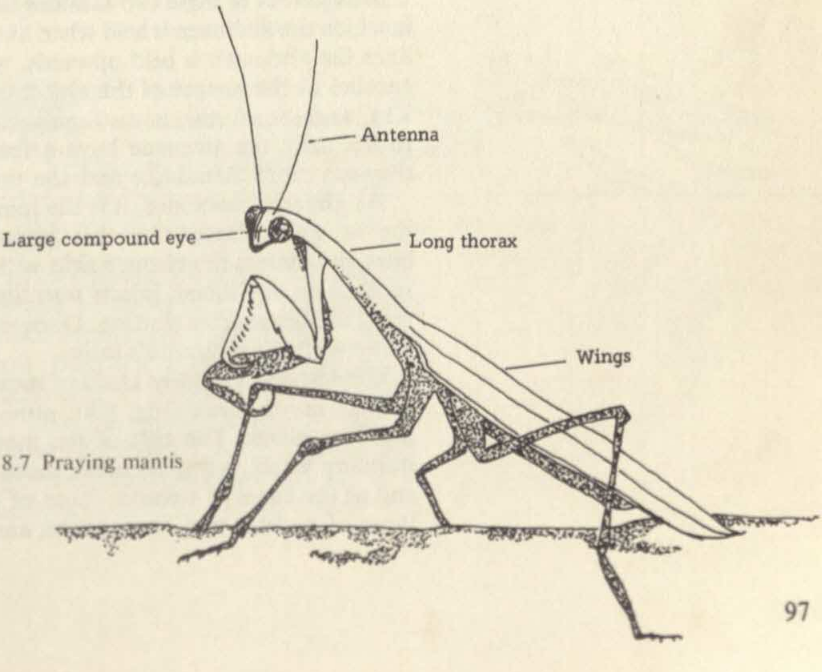


Fig. 8.7 Praying mantis

The Mosquito or Gnat

While mosquitoes are found all over the world, there is no doubt that they are best known in the tropics, where they have considerable economic importance, mainly as a result of the diseases they carry, such as malaria, yellow fever, dengue fever, and filariasis or elephantiasis. These diseases are transmitted by the mosquito biting and sucking blood from an infected person and giving the disease later to another person through another bite.

It should be pointed out, however, that all this is done by the female mosquito, for while both the male and female can feed on nectar or other sweet juices from plants, it is only the female which in addition can feed on blood. It is claimed that the female mosquito has a greater tendency to suck blood in the tropics than in temperate climates.

This is probably why the incidence of malaria is so high in the tropics, with particular reference to the West Coast of Africa where less than a century ago very many Europeans died from the fever. This gave to the Guinea Coast the name of 'White man's grave', but thanks to the discovery of quinine and similar drugs the West Coast is now virtually a 'White man's paradise'. Africans are generally immune to yellow fever as a result of their contact with the disease. Other people have to acquire immunity by inoculation which must be repeated every few years.

Structure and Mode of Life. Mosquitoes belong to the order of *Diptera*, which are characterized by having only a single pair of wings. The buzzing noise with which mosquitoes disturb us at night is due to the beating of their wings and not to 'singing'. There are three well-known names among the mosquitoes: these are *Anopheles*, the carrier of malaria; *Culex*, the carrier of filariasis or elephantiasis; and *Aedes*, the carrier of yellow fever. These belong to only two families of mosquito: *Anopheles* to the family *Anophelines* and the other two, *Culex* and *Aedes*, to the family *Culicines*.

Mosquitoes of these two families can be distinguished by the position in which the abdomen is held when at rest, for in the case of the Anophelines the abdomen is held upwards, whereas in the Culicines it is held parallel to the surface of the object on which the insect is resting (Fig. 8.8). *Aedes* can further be distinguished by white stripes on a black body. In the male the antennae have a feathery appearance, in the female they are more thread-like and the proboscis is longer.

As already mentioned, it is the female mosquito which sucks blood; she is well adapted for this purpose. When the female mosquito bites she pierces the victim's skin with her sharp proboscis and, before sucking up any blood, injects into the wound a little saliva which prevents the blood from clotting. Disease germs pass into the blood-stream along with the mosquito's saliva.

Life-history. The three kinds of mosquito mentioned above have very similar life-histories (Fig. 8.8), although they differ slightly in their breeding places. The eggs of the mosquito are laid on the surface of standing water, but quite often those of *Anopheles* are found in pools and at the edges of streams, those of *Culex* in any standing water, and those of *Aedes* in tins, water-tanks, and other containers near the house.

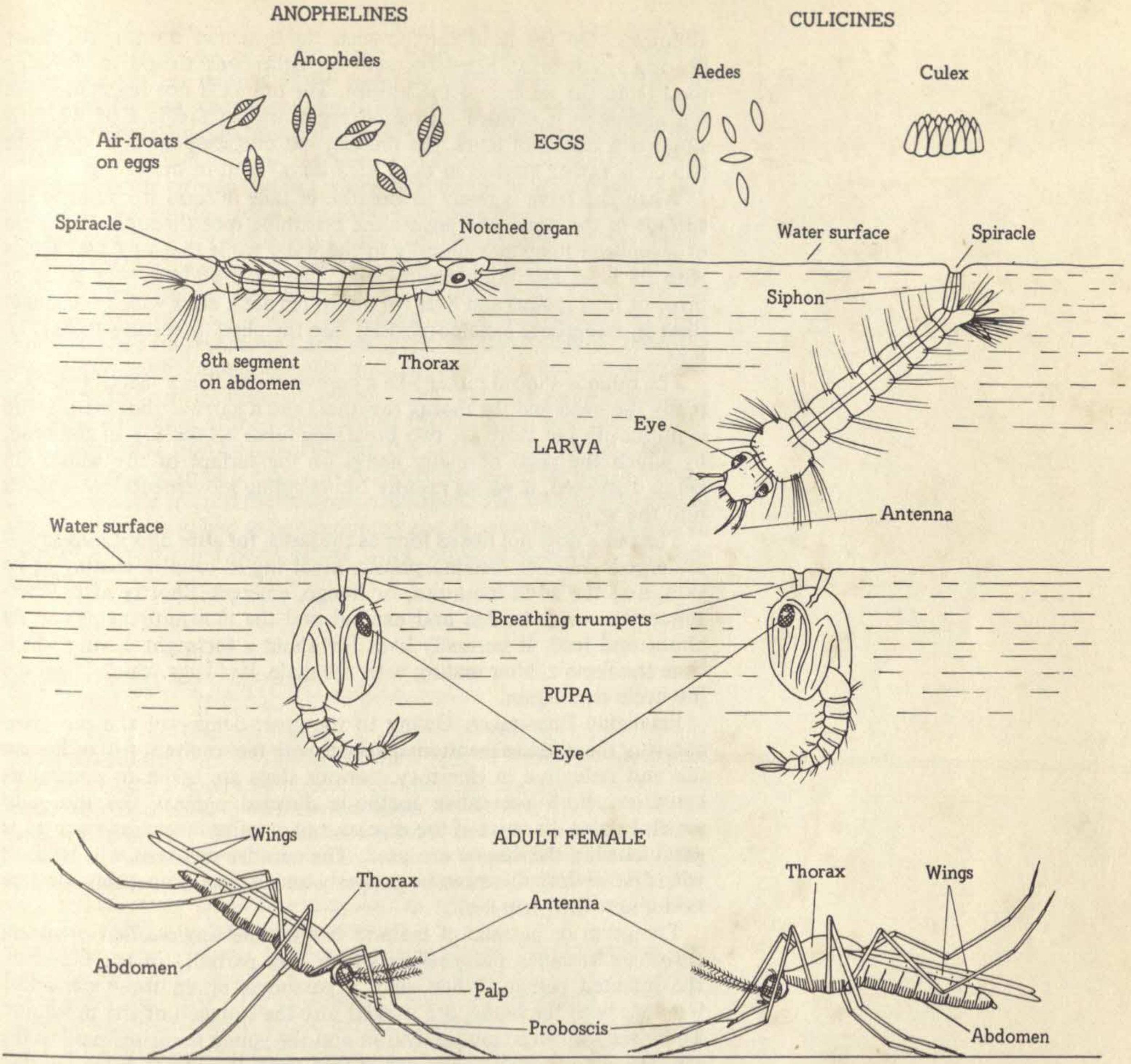


Fig. 8.8. Habit and life-history of *Anopheles* and *Culex* mosquitoes

In addition, eggs may be found in any position where water collects, such as the hollow formed in the axis of leaves of grass, banana, and cocoyam, and in tree trunks. Since mosquitoes hide in dark places, standing water in such places seems preferable to them for breeding.

The eggs of the mosquito are boat-shaped. Those of *Anopheles* have each a small bulge—the air-float. Like the eggs of *Aedes*, the eggs of *Anopheles* are laid singly while those of *Culex* are stuck together and look like a small raft. After a day or two the egg hatches into the larva which moves in rapid jerks. Its body is divided into head, thorax, and

abdomen. On the head can be seen the eyes and mouth, the latter bearing small brush-like structures on either side to aid in directing food from the water into the mouth. The thorax is not segmented but the abdomen is divided into nine segments, on the last of which is situated a bunch of hairs. On the last but one segment is a long tube (which is rather marked in the *Culex* larva) used in breathing.

When the larva is ready to breathe or take in food it comes to the surface of the water and pushes the breathing tube through. The larva of *Anopheles* floats horizontally in the water while that of *Culex* hangs with its head and body downwards. The larva undergoes a series of three or four moults and lives for about ten days, after which it changes (that is, undergoes metamorphosis) into the pupa or resting stage (Fig. 8.8).

The pupa is shaped rather like a comma with a large 'head' (which is really the head and the thorax together) and a narrow abdomen. There is no mouth but there are two breathing tubes on the top of the head, by which the pupa normally hangs on the surface of the water. On being disturbed, it swims rapidly by wriggling movements downwards into the water.

The pupa does not live as long as the larva, for after about two days it undergoes another metamorphosis, involving as usual a casting of its skin, and the adult mosquito, or imago, emerges. Shortly after emergence the wings harden and expand and the mosquito begins to fly about and feed. It normally lives for about a fortnight during which time the female, after mating with the male, lays eggs which begin the life-cycle over again.

Economic Importance. Owing to the great danger of the mosquito carrying the diseases mentioned above, with the resultant toll of human life and reduction in efficiency, various steps are taken to control its activities. Both preventive methods directed against the mosquito which carries the germ of the disease and curative measures against the germ causing the disease are used. The curative methods will be dealt with first. Before these can be properly understood, something must be said about the germ itself.

The germ or parasite of malaria is a minute single-celled organism (protozoan) called *Plasmodium* which lives partially in the blood of the infected person. When such a person is bitten these parasites, together with the blood, are sucked into the stomach of the mosquito. There they undergo multiplication and the young parasites pass to the salivary glands where they are stored until the insect bites another person and introduces some of them into his blood. Drugs are now available that kill the parasites when they get into our blood. Quinine was the first to be discovered but now we have drugs like 'Mepacrine', 'Daraprim', 'Paludrine', and others.

Since prevention is better than cure, it is to the preventive measures against the mosquito that we must all pay more attention. The more important of these are the draining of breeding places and the destruction of the larvae, and not merely the use of mosquito-nets. Every effort should be made to remove likely breeding places, such as swamps, bush near houses, and old tins.

Any large quantity of water for use should be effectively sealed. As

for the destruction of the larvae, the usual method is that of spraying kerosene to form a film on the water. Being a paraffin, the kerosene lowers the surface tension of the water so that it is no longer able to support the larvae when they come to suspend themselves on the surface in order to breathe. The larvae therefore sink in the water and are suffocated. Another method that has been used where drainage is impracticable consists in introducing fish which feed on the mosquito larvae (see Fig. 2.1). As for the adult mosquitoes, insecticides like D.D.T. and 'Gammexane' can be employed to reduce their numbers in the house.

From these considerations it is clear that the mosquito is of considerable economic importance, particularly in tropical areas. Because of the mosquito we spend money on 'Paludrine' and similar drugs, on mosquito-nets and on insecticides, and we spend time in destroying breeding places. Ill-health caused through malaria makes us less efficient and may stop us from working altogether, and there are some interesting historical examples of the way in which the mosquito has disorganized man's schemes. For example, during the construction of the Panama Canal, work had to be temporarily stopped because of the toll in human life and energy from mosquito-borne diseases. The breeding places in the neighbourhood had to be eliminated and the number of mosquitoes reduced to vanishing point before work could be continued to completion.

SUGGESTED PRACTICAL WORK

1. *The Structure of Insects.* Try to make your own collection of each of the insects described in this chapter and to study them at first-hand. Also make your own observations, keep a record of where the insects are found, and watch their behaviour in such environments. (*Note.* It is not necessary to study the individual joints of the mouth-parts or other limbs.) To obtain mosquitoes, place a jar of water containing a rotten leaf in a shady place, and examine it daily until you find mosquito eggs in it. Then cover it with a cloth and watch the stages of development as in No. 3 below. Use the adult stage for studying the parts of the mosquito.

2. *Preservation of Insects.* If, after examining the living insect, you wish to study the parts more closely, kill it with chloroform in a bottle with a close-fitting screw cap. Pass a pin through the thorax and fix it on a board. To store the insect after study, use 70 per cent alcohol or 5 per cent formalin, but it is often best to preserve it dry. To do this, first put the insect in a desiccator for a few days to dehydrate it and then place it in an insect-proof box and paint it with mercuric chloride dissolved in alcohol. Give the scientific and common names of the insect on the label, as well as the date of collection.

3. *Study of Life-history.* You can also study in the laboratory the life-history of any of the insects in which you are particularly interested. For this purpose a simple breeding case, such as an aquarium or even a jam-jar covered with wire mesh, can be used. Place it in water to prevent disturbance by ants. It is possible to obtain the various stages from the egg to the adult in a breeding case like this. Ensure that adequate quantities of fresh plant material are provided daily for the nourishment of the larval stages of the insects. It is necessary to clean out the breeding case every few days.

4. *The Cockroach.* Search for the egg-cases of the cockroach in dark, sheltered places—for example, beneath window-ledges, table-tops, and cupboard shelves—particularly in kitchens. The egg-cases are up to 1 cm long, and very dark brown. Place one egg-case in a screw-top jar and observe it every day. How many small cockroaches (nymphs) hatch out of the case? Can the small cockroaches fly?

5. *The Grasshopper or Locust.* (*a*) Examine the long hind-legs for the organs used in producing sound.

(*b*) Obtain some locusts and carry out various feeding experiments with them. Feed one group of insects on dry grass, another group on fresh grass, and a third group on dry bran. Weigh the locusts at the start of the experiment and thereafter at weekly intervals. Which group of locusts gains most weight? (Locusts can be conveniently weighed in a muslin bag.)

6. *Mosquito.* Fill two jars with water containing mosquito larvae and pupae, and spread a little kerosene or oil on the surface of the water in one of the jars. Note how long the larvae and pupae survive in each jar. Explain the results you get.

CHAPTER NINE

Insects: The House-fly, the Tsetse-fly, and the Citrus Butterfly

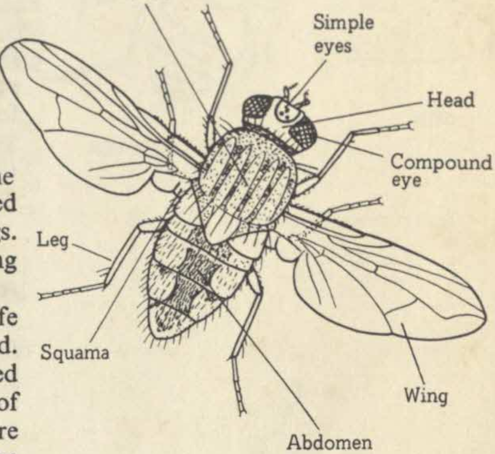


Fig. 9.1. External features of house-fly

The House-fly

THE house-fly, *Musca domestica* (Fig. 9.1), is an insect belonging to the same group (*Diptera*) as the mosquito and the tsetse-fly. As mentioned above, these insects are noted for possessing only one pair of wings. Their mouth-parts, such as the labium, which usually forms a long proboscis, are also adapted for sucking or piercing.

There is probably no insect more commonly encountered in daily life in the tropics than the house-fly, which interferes so much with our food. The body of the fly is grey in colour with black streaks, and is covered with bristles that give it a hairy look. It is divided into the three parts of head, thorax, and abdomen, as with all insects. The compound eyes are particularly large and in addition there are three small simple eyes on top of the head. The two antennae are rather short. The mouth-parts are much modified, forming a tube or proboscis for sucking.

On each of the three segments of the thorax there is a pair of jointed walking legs, with two small claws at their tips which help in walking on rough surfaces. Two small pads are found between the claws (Fig. 9.2), and these secrete a sticky substance which attaches the fly firmly to its support when walking on smooth surfaces, even when its body is upside-down. The single pair of wings are found on the second segment of the thorax. These wings are held horizontally along the abdomen when the insect is resting. The abdomen is rather short and appears to have only four segments.

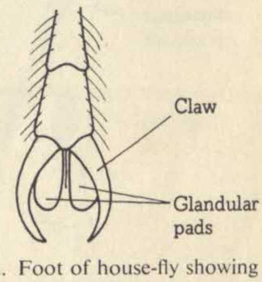


Fig. 9.2. Foot of house-fly showing pads

Mode of Life. The house-fly lives on fluid foods and its mouth-parts are adapted to the nature of the food. The long proboscis is not simply pointed at its tip, but has two flaps at its end with grooves along which the fluid from the food runs into the main tube (Fig. 9.3). Although the fly seems adapted only to fluid foods, it can also tackle solid foods which are fairly soluble, such as sugar. In this case, by exuding a drop of fluid from the alimentary canal through the proboscis, the fly first dissolves the sugar at one spot and then sucks up the resulting solution. This habit of 'vomiting' fluid from the gut and the fact that the fly may feed on decomposing or faecal matter, explains why the house-fly is such a disseminator of diseases, particularly those of the alimentary tract.

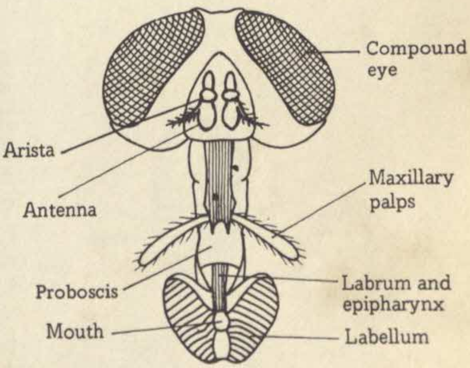


Fig. 9.3. Proboscis of house-fly for sucking

Life-history. The female fly lays her eggs in any decomposing matter, such as a rubbish-heap, and five or six batches each of about a hundred eggs may be laid. The eggs are small and white and, after about a day, they hatch out into the larvae or maggots (Fig. 9.4). These have neither head nor legs and the body, which consists of twelve segments, tapers

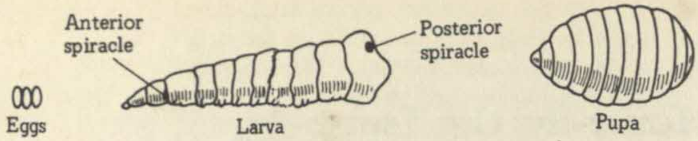


Fig. 9.4. Stages in the life-history of house-fly

from the hind end to the front. A hooked structure situated on the first segment enables the larva to crawl along and to feed, not only on liquid food but also on solid organic matter which is first liquefied by enzymes. The larva may make its way farther into the rubbish-heap and is able to breathe by means of a pair of spiracles situated at each end of the body.

At pupation the body of the larva contracts and the skin hardens and turns brown. One peculiar feature here is that in the larva, after the second of the two moults which take place, the skin is not shed but continues to enclose the pupa. This is the brown covering called the *puparium*. Very considerable changes then take place in the body of the pupa which after about four days changes into the adult, or imago, inside the puparium. The imago has to free itself from this covering and to do this it uses a bladder-like structure filled with blood which projects from the front of its head. After breaking through the puparium the adult fly emerges.

Economic Importance. As already mentioned, flies will feed on any fluids, including decomposing organic material and even faeces. Thus, before settling on our food, a fly may already have been contaminated with filth. This may be on the sticky pads of the feet or on any part of the hairy body, since particles of dirt easily cling to its surface. Apart from the dirt on the outside of its body, the fly can also 'vomit' out filth from its alimentary canal on to our food when it wishes to feed. This habit can bring all sorts of bacteria to us when we eat food contaminated in this way, and diseases like diarrhoea, typhoid fever, cholera, and dysentery are all spread by the house-fly.

The female house-fly seeks dead organic matter in which to lay her eggs and, in order to reduce the fly population in our area, we should make sure that we destroy any such rubbish, preferably by burning, since it is not effective merely to bury it. Food should not be left exposed but should always be kept covered until required. When there is any food left over it should not be thrown away haphazardly but should be placed in covered refuse tubs. Faeces should be disposed of immediately, and even in latrines the holes should always be covered after use. Fly-traps are also very useful if well maintained.

The Tsetse-fly

The tsetse-fly (Fig. 9.5) belongs to the same group, the Diptera, as the house-fly, and is thus basically similar to the latter in a number of ways. One way in which the tsetse-fly can be distinguished from the house-fly is that when at rest one of its wings lies across the other, like a pair of scissors. The tsetse-fly is found throughout tropical Africa, and even in parts of South Africa, where it has considerable economic importance

in spreading a chronic infectious disease, which can be fatal, called sleeping sickness. There are some three or four species of the insect which are known to spread the disease, but a notable one is *Glossina palpalis* (Fig. 9.5).

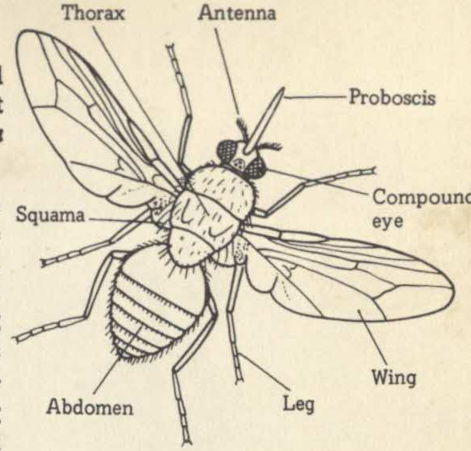


Fig. 9.5. Tsetse-fly (*Glossina palpalis*)

Mode of Life. The tsetse-fly is a blood-sucking insect which lives where shade and water are available, such as woods and forests and the banks of rivers or standing water in the dry savannahs. The insects cannot tolerate strong light and are much attracted by moving objects.

The fly carries large numbers of the organism which causes sleeping sickness. This is the protozoan parasite *Trypanosome* (Fig. 9.6) which is transmitted to mammals, especially man and cattle, as well as to other animals such as birds and reptiles, when the insect sucks blood during its bite. When the trypanosomes get into man or cattle they multiply in the blood-stream within a few weeks and produce waste products (*toxins*) which cause sleeping sickness.

It should be remarked, however, that not all mammals infected with the parasite suffer from the disease. This in fact means that these animals, such as antelopes, may be a source of danger to us because they can act as reservoirs for the parasite. In this way an uninfected tsetse-fly may become infected when it bites such an animal and may then pass the parasites on to man.

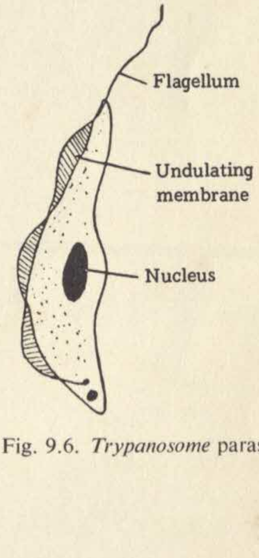


Fig. 9.6. *Trypanosome* parasite

The mouth-parts of the tsetse-fly are adapted for sucking. When the fly bites it thrusts its proboscis into the skin of its victim and draws in blood. This enters the fly's stomach and, if its victim is already infected, some of the parasites are also ingested. The parasites multiply in the insect and finally collect in the salivary glands. When the fly bites a healthy person the parasites are introduced into his blood-stream and produce sleeping sickness. The name 'sleeping sickness' was given to the disease because of the somnolent condition of the patient in the terminal stages. In the end the patient may die.

Life-history. (See Fig. 9.7.) Mating between the male and female tsetse-fly results in only one egg being fertilized in the female, and instead of laying this egg the female keeps it inside her body until it hatches into the larva. About eight days later the larva is then 'born' in a dry, shady spot. It is worth noting that this habit of keeping the young one in the body of the female until it is well advanced before 'bringing it forth' is typical not of insects but of mammals, as we shall see later. It is called *vivipary*.

The larva of the tsetse-fly is a white, cylindrical object with two knobs, bearing breathing pores. It quickly makes itself a tunnel about two inches deep and burrows into this to undergo a series of moults. After about ten days, in warm weather, it changes into a pupa, and this stage lasts for about three weeks before giving rise to the adult fly. As soon as the adult fly emerges from the pupal case, it climbs up its tunnel to the surface, where it dries its wings and flies away.

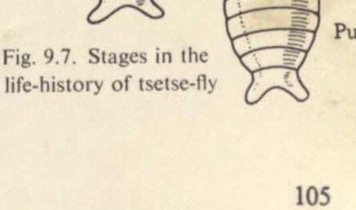


Fig. 9.7. Stages in the life-history of tsetse-fly

Economic Importance. The tsetse-fly, as mentioned above, has considerable economic significance in tropical Africa mainly as a result of the sleeping sickness which it transmits.

Firstly, because of the weakness and general reduction in health and output which the disease brings, the patient is rendered useless for his

normal duties. This means a loss of a considerable sum of money throughout the year by the country; productivity is thereby reduced. Secondly, sleeping sickness kills hundreds of people each year. In 1903 it killed nearly a quarter of a million of the inhabitants around Lake Victoria in East Africa. The disease also kills thousands of cattle. The latter means the loss of a great quantity of meat which provides us with much of our protein. This is one main reason why tropical Africa is so poor in this vital food substance. Ultimately this means poorer health for the inhabitants.

Finally, because of the tsetse-fly and sleeping sickness, it has not been possible to inhabit and develop large areas in tropical Africa. As a result a large amount of the wealth of the country is locked up in these areas. In parts of Northern Nigeria whole populations have had to move from badly infected areas. Since the population is increasing in tropical Africa and considerable information on the life-history and mode of life of the tsetse-fly is now available, various countries in Africa are spending money to open up these areas.

The most effective method of control has been that of clearing low bush, which provides shade and maintains dampness along river-banks and other breeding places of the insect. In Northern and Upper Ghana this has been successfully done in recent years. Another worth-while method of control has consisted in killing off all the antelopes in areas where cattle are bred in large quantities. This has been tried in parts of East Africa. It destroys the potential source of supply of the parasites. Drugs are available for the treatment of man and animals during the early stages of the disease. It is also wise to avoid spending too much time in places that are favourable to the breeding of the tsetse-fly without adequately covering the body.

The Citrus Butterfly (or Common Papilio)

The order *Lepidoptera* is a group which includes the moths and butterflies and, as the name implies, its members are distinguished by the numerous tiny scales which cover their bodies and wings. These scales contribute to the brilliant colours of many butterflies, either by those coloured substances called pigments which they may contain, or by their action in separating white light into its many constituent colours, which they reflect. The bright, iridescent colours of many butterflies are produced in this second way.

Butterflies and moths are very similar in structure and life-history, but there are a few striking differences (Fig. 9.8). In the first place, while butterflies may be found flying about during the day moths are generally found only at night. Again, butterflies have thin, delicate bodies and bright coloration, whereas moths have rather drab, thick bodies and dull coloration. We can also distinguish between them by examining them when at rest, for in this position the wings of the butterfly are found to be folded vertically over the back, while in a moth the wings lie horizontally.

On closer examination we find more differences. An obvious one is that while the antennae of butterflies have knobbed tips, those of moths are rather pointed as well as being feathery. Furthermore, while

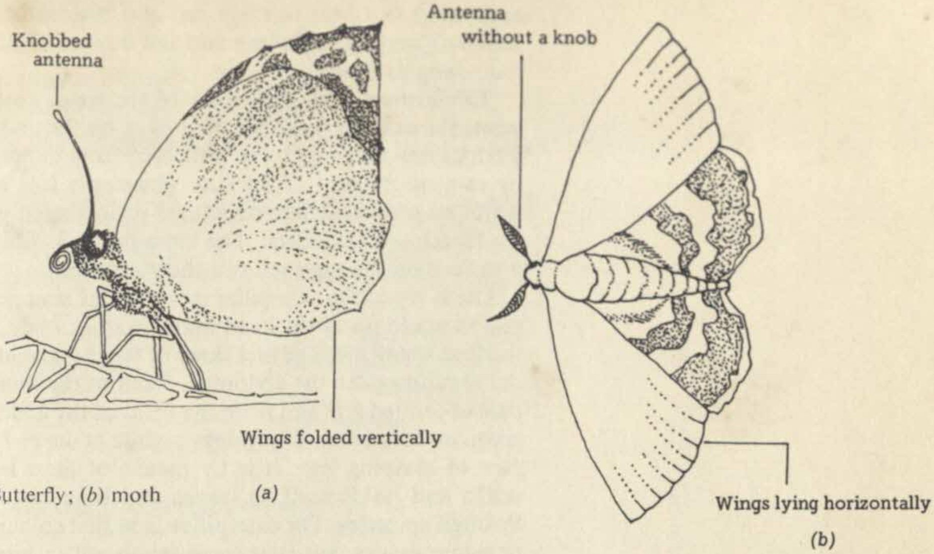


Fig. 9.8. (*a*) Butterfly; (*b*) moth

the fore- and hind-wings of a butterfly are separate and not joined in any way, the situation is different in the case of a moth, where the fore- and hind-wings are locked together. A common tropical moth is the oleander hawk moth.

Butterflies and moths pass through a rather complicated life-history which involves three sharply defined stages. This constitutes complete metamorphosis. The eggs develop to form those larvae which we call caterpillars; these usually have elongated, worm-like bodies, a number of legs and claspers, and biting mouth-parts which enable them to feed on the leaves of plants. The larva feeds very actively, and it is during this phase that the principal growth of the insect takes place. Eventually, the larva ceases to feed, and its movements become more sluggish and finally cease altogether. At this point the larva passes into the next stage, which is known as a pupa, or *chrysalis*. This is a resting stage during which the body of the larva becomes transformed into that of the adult insect.

Finally, the adult insect emerges from the tough casing which protects the pupa. The insect does not increase greatly in size during the rest of its life. Butterflies and moths feed on the nectar in flowers, which they reach with mouth-parts modified into a long, coiled sucking-tube.

Those butterflies which are known as citrus butterflies, or citrus swallow-tails, present a fairly typical life-history which will serve to illustrate the features of the order Lepidoptera as a whole. These butterflies belong to the genus *Papilio* and the full scientific name of the species which we are going to describe is *Papilio dardanus*.

Mode of Life. Citrus butterflies (Fig. 9.9) can often be found in large numbers during a dry period of the year in the neighbourhood of orange and other citrus fruit trees. They are beautifully coloured, with a general colour of greenish black with yellow patches. (There is also the green-banded *Papilio* which is similar to the common *Papilio*, but has blue-green patches in place of yellow ones.) A little tail is found at the end of

each wing and near this is a red and blue spot. They feed by sucking nectar from garden flowers and the flowers of citrus trees by means of their long proboscis.

Life-history. The life-history of the citrus butterfly (Fig. 9.9) begins when the adult females lay their eggs on the underside of the leaves of a citrus tree, in order to be protected from damage that may be caused by rain or the heat of the sun. The newly laid eggs are tiny, rounded white or greenish-white structures which hatch within a few days into the larvae or *caterpillars*. The larva has powerful mandibles which help it to feed on the egg-shell and the young leaves.

The body of the caterpillar is worm-like in appearance and rather soft and is made up of the head and the main body, which is divided into thirteen segments. The first three of these segments form the thorax and the remaining ten the abdomen. Each of the thoracic segments bears a pair of jointed legs and from the third of the abdominal segments to the sixth are four pairs of 'pro-legs', while at the end of the body there is a pair of clasping legs. It is by means of these legs that the caterpillar walks and holds itself on leaves and branches. Breathing takes place through spiracles. The caterpillar is at first coloured brown with yellow or white marks, but later turns green with white stripes. On the head are six small simple eyes, instead of the compound eyes of the adult. When the caterpillar is disturbed or frightened it shoots out two red horns from its head.

After a few days the caterpillar undergoes moulting. This involves the splitting of the skin covering along the back near the head and the emergence of the caterpillar from the covering. This is necessary since the skin is not elastic and growth of the caterpillar would otherwise be impeded. Moulting is repeated three or four times, and after each moult the caterpillar feeds actively and grows rapidly. After about three weeks, the caterpillar is about one and a half inches long, and at this point it stops growing and is ready to change into the next stage.

Before changing into the next stage the fully grown caterpillar leaves the leaf and finds a more solid part of the plant, such as the stalk of a leaf or a twig. There it spins a covering of silk (called a *cocoon*) round itself. The silk comes from silk-glands in the head of the caterpillar, in the form of a fluid which hardens when dry to form silk. Inside the cocoon the caterpillar undergoes a final moulting, but this time quite a different structure emerges. This is the pupa. It has a number of the features of the adult butterfly and is much shorter than the caterpillar. The pupa is usually brownish in colour with flecks of green, and this protective coloration enables it to merge with the stem to which it is attached. The pupa consists of a hard case and is fixed at the hind end to a branch and supported at the top end by a silken thread.

The pupa is merely a resting stage, and it remains virtually motionless while the organs of the adult butterfly are being formed. In fact the wings, eyes, antennae, and feeding apparatus of the adult may be seen through the skin of the pupa after about a week. This activity completed, the pupa undergoes a change into the adult, or imago. As mentioned above, the changes from one developmental stage to the other, such as the change from the caterpillar to the pupa, and from the pupa to the adult, are referred to as *complete metamorphosis*. In the change from

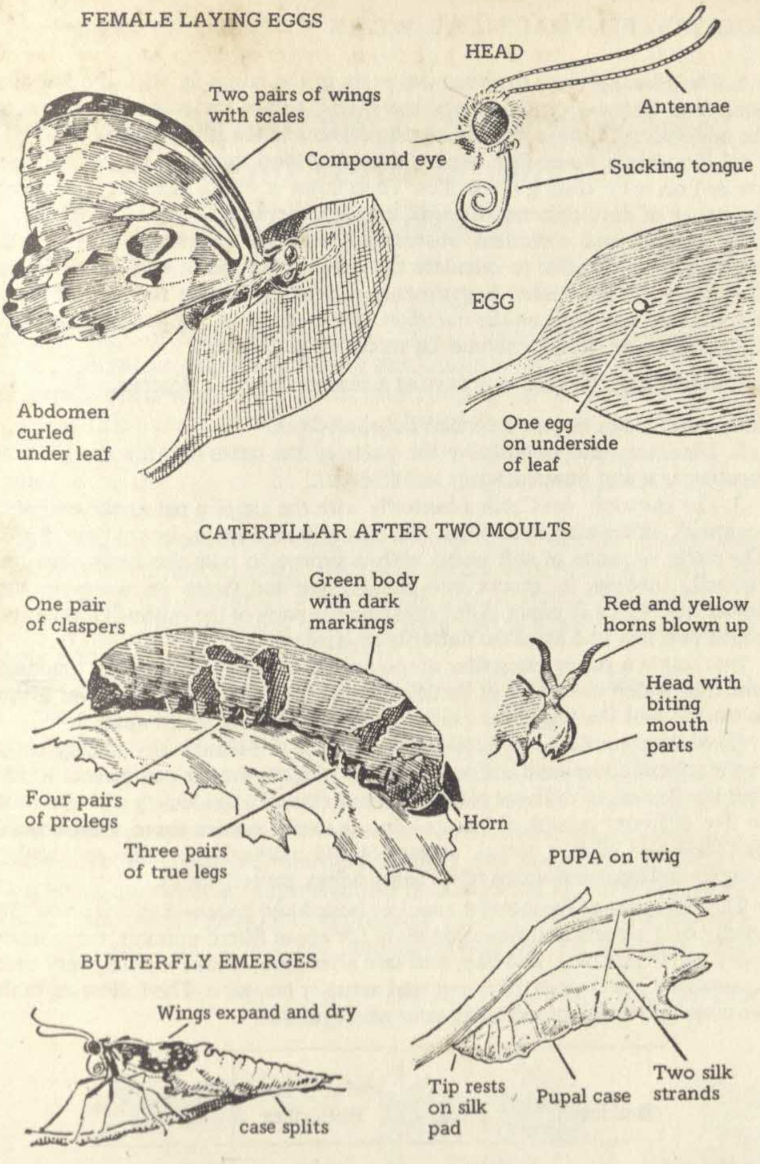


Fig. 9.9. The life-history of citrus butterfly (reproduced from *Animal Life in the Tropics* by E. M. P. Walters, Allen & Unwin)

pupa to imago the silky covering of the pupa splits along its upper surface and the young imago with small crumpled wings crawls out. After resting for about two hours, it slowly stretches its wings and is able to fly off.

Economic Importance. The citrus butterfly is a pest on young citrus trees, for the caterpillar destroys the leaves. This may result in poor development and reduced fruiting.

SUGGESTED PRACTICAL WORK

1. *The House-fly.* (*a*) Examine the parts of the house-fly with the aid of a hand-lens. Remove one of its legs and examine them under the low power of the microscope, noting particularly the claws and the sticky pad.

(*b*) To obtain house-flies, expose decaying food for some days until eggs are laid on it by visiting house-flies. Then cover it with a glass jar and watch the stages of development; examine the eggs, larvae, and pupae of the fly.

By careful and consistent observation (that is, examination at *regular* intervals) it is possible to calculate the actual duration of each stage in the life-history of this insect. Experiments can be devised to test the effect of temperature and light on the duration of the egg stage, the larval stage, and the pupal stage. Results should be recorded as follows:

x house-fly eggs hatched in y days at a temperature of z degrees.

Class results can also be recorded in graph form.

2. *The Tsetse-fly.* In studying the parts of the tsetse-fly note the piercing mouth-parts and how the wings are folded.

3. *The Butterfly.* (*a*) Catch a butterfly with the aid of a net at the end of a long stick, kill it with chloroform and mount it on a setting board (Fig. 9.10). The latter is made of soft wood with a groove to take the body. Pin the butterfly through its thorax into the groove and fasten its wings to the board with strips of paper. After studying the parts of the butterfly, place the board in a box and leave the butterfly to harden.

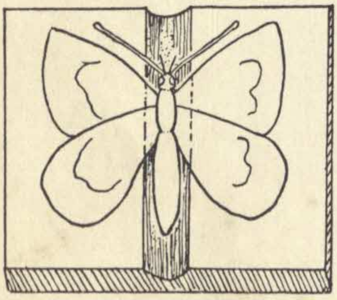


Fig. 9.10. A setting board for insects

(*b*) Obtain a young caterpillar of the orange butterfly, keep it in a breeding case and watch the stages of its development. Follow the suggestions given in section 3 of the Suggested Practical Work at the end of Chapter 7.

(*c*) *Pollination Exercise.* This exercise can be performed very conveniently in the school compound. Its purpose is to observe the various insects which visit the flowers of different plants. First of all, learn to identify by sight four or five different groups of insects—for example, beetles (hard wing-cases), flies (one pair of thin wings), butterflies and moths (large, coloured, scaley wings), and bees and wasps (thin, filmy wings, striped body).

The next part of the exercise requires pencil and paper—and patience! Sit quietly near a particular flowering plant for about fifteen minutes, three times a day (early morning, mid-day, and late afternoon). Make a note every time a particular insect visits the flower and actually *touches* it. The following table is a convenient way of recording your observations:

	Beetles	Flies	Moths and Butterflies	Bees and Wasps
8 a.m.		√		√√√
12.30 p.m.		√	√√√√√√	
5 p.m.	√√√	√	√√√√	√

These results can easily be converted to percentage figures for easier reference.

Other important information should also be recorded—for example: name of flower visited; colour of flower; presence or absence of scent; weather conditions; and time of year.

CHAPTER TEN

Insects: The Greenfly, the Honey-bee, the Mound Termite, and the Ladybird Beetle

The Greenfly (*Aphis*)

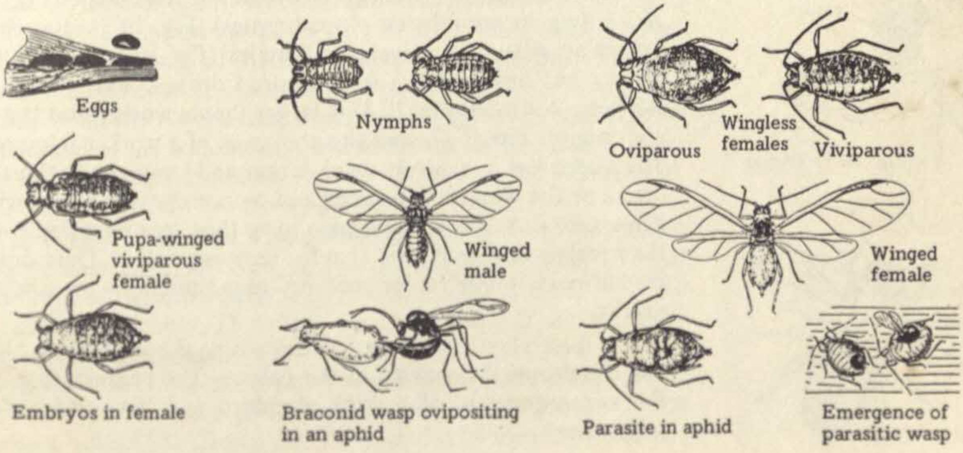
THE greenfly, or aphis, and the scale insects belong to a group known as the *Homoptera*. These are mostly small insects with piercing and sucking mouth-parts which they use in puncturing plants to feed on the sap. The greenflies are thus sometimes referred to as plant lice. Some of these insects have wings which are membranous and generally lie sloping over the side of the body; there are, however, certain forms which are without wings.

The aphis is commonly wingless with a rather delicate body (Fig. 10.1). It is often found in large numbers on the under-surface of leaves, or on the young shoots of a variety of plants, especially cotton and citrus plants. The proboscis is rather long and is adapted for piercing plants and sucking juices from them.

Mode of Life. As the greenfly sucks the sap of plants, it secretes much of it as a sweet fluid called 'honey-dew' which is greatly relished by ants. Thus ants are often found among the greenflies and, in order to get more of this juice, they even protect the greenflies and carry them about to new feeding grounds. By the secretion of honey-dew, greenflies may clog up leaf-pores.

Life-history. Greenflies multiply rapidly and soon render the host plant weak and useless. Reproduction is carried out in two ways. In the first, the normal wingless kinds reproduce when they are fully developed, but their reproduction involves neither mating nor the laying of eggs.

Fig. 10.1. Aphis (by permission from *General Zoology* 3rd edition by Storer and Usinger, copyright 1957, McGraw-Hill Book Company Inc.)



Once every few days this type of aphis 'gives birth' directly to a small greenfly very much like the parent. This type of reproduction, which takes place without fertilization, is called *parthenogenesis*. We shall see another example in the worker of the honey-bee. In the greenfly parthenogenesis is a far more rapid method of reproduction than sexual reproduction.

The second method of reproduction in the greenfly appears to be dependent on food supply and climatic conditions. In this, wingless, parthenogenetic, viviparous females lay eggs from which come similar females, some of which, however, are winged. These winged females, which may fly off and infest other plants, will produce a certain number of parthenogenetic, viviparous generations after which sexual individuals appear. These mate sexually and lay eggs from which, after metamorphosis, wingless greenflies are produced.

Economic Importance. It is obvious from the life of the greenfly that it is an insect which causes a great deal of harm and destruction to economic crops such as cotton and citrus. Its methods of reproduction rapidly increase the number of insects and their mode of feeding soon renders the plant useless. Another way in which the greenflies injure plants is by blocking up the pores, through which the plant respires, with the honey-dew and a waxy substance which the insects secrete.

Greenflies may be controlled by cutting off and burning the infested parts of the plant. Another method is to wash or spray the plant with a mixture of kerosene, soap, and water; this suffocates the insects.

It should be mentioned that other destructive insects in this group are the cocoa aphis and the mealybug, which transmit swollen-shoot virus in cocoa plants.

Fig. 10.2. Queen bee

The Honey-bee

The honey-bee, known scientifically as *Apis mellifera*, is a well-known social insect and most species of bees live in a community, popularly called the *colony*. There are, however, a number of species which lead solitary lives.

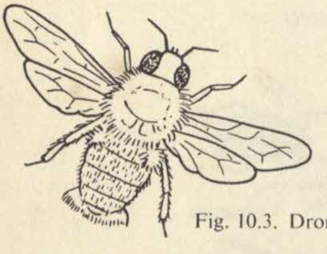


Fig. 10.3. Drone

Three types of individuals or 'castes' are present in the community. These are the *queen* (which is a fully developed female (Fig. 10.2), the *drones* (which are fully developed males) (Fig. 10.3), and the *workers* (which are sexually undeveloped females)(Fig. 10.4). A well-established colony has one queen, a few hundred drones, and several thousand workers. A drone (Fig. 10.3) is larger than a worker and the end of its abdomen is blunt, whereas the abdomen of a worker is more pointed. The queen has a relatively much larger and longer body than either the drone or the worker. The queen and workers possess stings whereas the drones do not. The workers also have their legs modified for cleaning their feelers and body, and also for carrying pollen. The honey-bee has mouth-parts modified for sucking, manipulating wax, and collecting nectar.

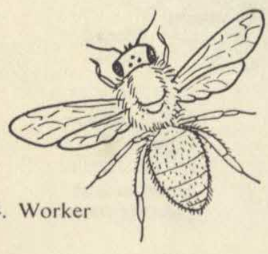


Fig. 10.4. Worker

The queen lays all the eggs of the colony, the workers do all the work, and the drones do nothing in the colony. The organization of work in the community is of a high standard and 'law and order' is well maintained.

Mode of Life. *The Queen.* It is often thought that the queen is the ruler of the colony. This is not correct because all her actions are controlled by the workers, even including her maternal duties. For example, it is the workers who decide how many eggs she is to lay, by regulating the amount of food they give her. The workers clean the queen and feed her on food which they have already digested. The queen rarely leaves the colony, except when she is old and has to vacate her position for a newly born queen; in this case she accompanies the *swarm* or mass exodus of workers to begin a new colony elsewhere. The new queen left behind in the hive may make a few brief flights to try out her wings shortly before making the *marriage-flight*, during which she mates with a drone. She then returns to the hive and starts laying eggs.

The Drones. These male bees do no work either inside or outside the hive but eat much of the food collected by the workers. Despite the fact that the drones do no work, if they are removed from the colony the enthusiasm of the workers and the queen for their work diminishes, and the whole 'spirit' of the colony is upset. The drones are even fed like the queen by the workers on easily digested food.

The role of the drones ends with the marriage-flight and mating of the virgin queen. Later they continue to live unmolested in the colony and, unlike the workers, are welcome in any other colony at any time. However, towards the end of the active season, the workers starve them and drive them out of the colony to die.

The Workers. These sexually undeveloped females are the labourers and the army as well as the rulers of the colony. They can, however, lay eggs when the colony happens to be without a queen for some time. In this case their eggs, which are not fertilized, hatch into drones. The worker bees are very active and defend the colony by attacking any intruders or invaders with the aid of their powerful stings. They gather nectar from flowers and bring it home in their honey-stomachs to be converted into honey.

Workers also collect pollen from the flowers and carry it home in the *pollen-baskets* which are situated on their third pair of legs (Fig. 10.5). This is mixed with honey to form 'bee-bread' on which all members of the colony feed. They fetch water and a sticky substance called *propolis* (which is a mixture of resins) from certain trees and use it in filling up cracks and repairing various parts of the hive. They ventilate and regulate the temperature of the home, keep it clean, and carry away debris and the bodies of any dead bees. Finally, they secrete wax with which they build the *combs*, they incubate the eggs, and also feed all other members of the community, including the larvae. It is obvious that the workers exhaust themselves by overwork in the colony and, as a result, they often live for barely six weeks.

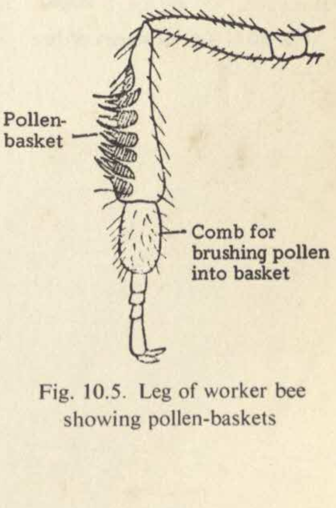


Fig. 10.5. Leg of worker bee showing pollen-baskets

Method of Communication. Honey-bees depend entirely on instinct, and they possess highly evolved sense-organs, such as those of sight, taste, and touch. These are particularly perfect in the workers who also govern in the community. Therefore, they often need to communicate 'announcements' or 'instructions'.

The worker bees are able, on returning to the hive, to announce the discovery of some delicious food such as pollen or nectar, in certain fruit trees or bushes like *Crotalaria*. They do this by means of a special

type of dance, during which other bees follow them, holding their feelers (on which are situated the organs of smell) against the bodies of the dancers to detect the actual scent of the nectar in question. There are special modes of dancing which indicate the distance and direction of the food source. The higher the concentration of the nectar the more vigorous the dance. When one of the bees following a dancer has received the information imparted by the dance it flies away to search for the nectar.

Life-history. As mentioned above, the queen does not leave the hive except when a new queen is hatched; then, in the company of a large number of bees, she leaves the parent colony in the swarm. The old queen settles elsewhere with the other bees and they build a new colony. But the new queen who remains flies out within a week's time on the marriage-flight accompanied by a large number of drones, one of which mates with her in the air. That drone dies soon after mating. She receives enough sperms, which she stores in a special sac, to fertilize all the eggs she may lay for several years. The queen, in contrast to the workers and the drones, may live for four or five years.

Returning to the colony after the marriage-flight, the queen proceeds to lay the eggs under the guidance of the workers. The queen can lay as many as 2000 or more eggs in a day, each egg being placed by her in a cell in the brood-combs. It is remarkable that the queen can lay as much as three times her own weight of eggs in a day! On the third day after it has been laid, the egg hatches into a larva (Fig. 10.6). Young worker bees called *nurses* feed the larva for the first three days of its life on rich food, called 'bee-milk', which they vomit out. If the larva is to become a worker, they stop the supply of this rich food after the third day and feed it for two and a half days on a mixture of pollen and honey. If the larva is to become a queen it is then fed on 'royal jelly' for five and a half days. The nurses visit each larva at the rate of 1300 a day! In either case, on the sixth day the larva is supposed to be fully grown and its cell is sealed with a mixture of pollen and wax. After two days the larva changes into a pupa, and within a week the pupa changes into the full-grown adult bee, which later emerges from the cell.

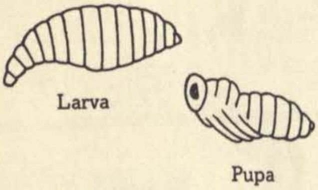


Fig. 10.6. Larval stages of bee

Economic Importance. Honey-bees prepare and store honey in some of the chambers of their comb to be used in time of need. This is removed and eaten by man or used in the preparation of various foods and drugs. The honey-bee is also one of the most important pollinating agents for a number of plants, including fruit trees (see Chapter 26).

The Mound Termite

Ants and termites are also social insects with a well-organized division of labour not unlike our own in the human community, where we have people specializing in different professions and all playing their parts in the maintenance of society as a whole. The white ants, or termites, can often be distinguished from true ants by the colour of the body (which is white), their preference for living in the dark, and by the similarity in size of the thorax and abdomen. They are commonly found in many tropical countries and have some economic importance.

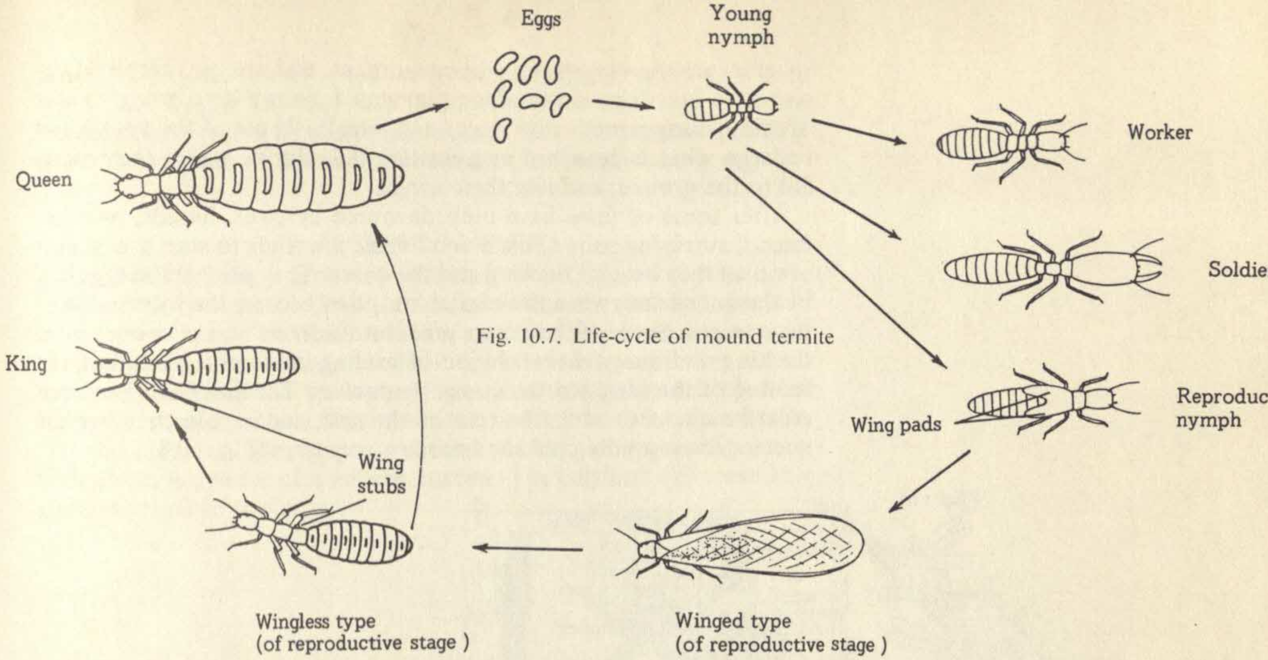


Fig. 10.7. Life-cycle of mound termite

Mode of Life. Some termites simply live in wood, while others live in the soil and build above ground the 'nests' called anthills or *termitaria.* These are the termite mounds which often rise to a height of 2½ metres or more, and are a striking feature on the farms and waste land in many tropical countries. The termitaria, as well as the chambers, underground channels, and covered tunnels above ground (through which food is carried), are constructed by using saliva to cement particles of sand together and are very strong.

The organization in the termitaria is based on three classes or 'castes' of termites: the *workers*, *soldiers*, and the *reproductives*. The workers (Fig. 10.7) have no wings and no eyes but have mouth-parts adapted for biting. They are small, sterile, and devoid of pigment and thus look rather pale. It is this look which probably originated the name 'white ants' for termites as a whole. With the aid of the young reproductives, the workers do all the work of the nest. They build and repair the nest, keep it clean, rear the young ones, fetch food and feed the soldiers, the king, and the queen, none of whom can feed themselves. The food, which consists of cellulose from dead leaves, is first chewed, swallowed, and digested by the workers who virtually vomit it out in order to feed the other inmates of the anthill.

The soldiers (Fig. 10.7) are also without wings or eyes and are sterile, but are pigmented. They are much larger than the other classes and have bigger heads with rather powerful jaws. With these the soldiers attack and drive away any animal that strays into the nest, although in some species of termite the soldier has no strong jaws but drives away intruders by squirting an unpleasant fluid at them through a special tube on the head.

Life-history. The reproductive forms (Fig. 10.7) are the only class with two pairs of wings. They are the kings and queens and, as the names

suggest, are the only group with sex-organs, and are thus fertile. They also have functional eyes and are pigmented. Soon after a heavy shower of rain, young reproductive males and females fly out of the anthill and undergo what is described as a *nuptial flight* during which they mate, fall to the ground, and lose their wings.

After some of them have been devoured by birds, lizards, or other insects, surviving pairs of male and female are ready to start a new nest of which they become the king and the queen. They protect the eggs laid by the queen and, when these hatch out, they become the sole nurses of the nymphs. Some of these later grow into workers and take over from the king and queen the whole job of feeding in the nest, including the feeding of the king and the queen themselves. The latter are kept in a separate chamber at the bottom of the nest, and in this chamber the queen grows rapidly until she becomes very large (Fig. 10.8).

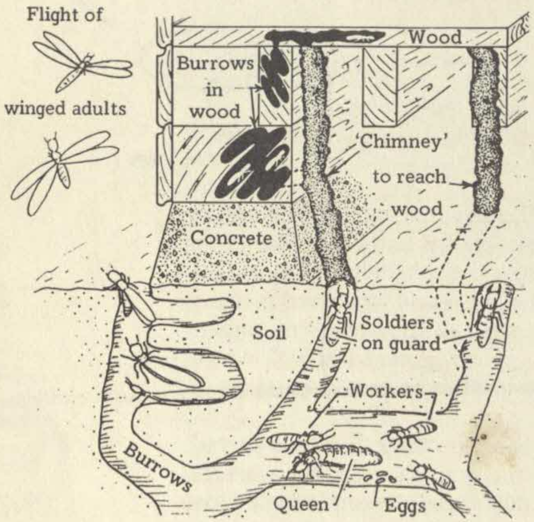


Fig. 10.8. Termites' nest (by permission from *General Zoology* 3rd edition by Storer and Usinger, copyright 1957, McGraw-Hill Book Company Inc.)

Most of the queen's size is due to her enormous abdomen, since her head and thorax remain very small. The abdomen is full of eggs which she later lays at the rate of about sixty per minute. The eggs, when laid, are carried away and looked after by the workers. The queen lives for several years and her only occupation is producing eggs. The king remains her permanent mate and grows smaller and smaller. When the eggs hatch out the workers look after the young till maturity. Thus the organization of the nest goes on until the next nuptial flight of young male and female reproductives sends some members out to begin new colonies.

Economic Importance. Termites are of some economic significance in our lives. They feed on plants and trees including some which are useful to us. In particular, they destroy timber in buildings, causing us considerable expense in their replacement. Few hardwoods, except ironwood and the mangrove, are hard enough to escape damage by the termite. Another economic significance of termites, this time of a

beneficial nature, is their habit of feeding on fallen leaves and dead vegetation. In this way they help to enrich the soil since they speed up the decay and return of plant remains into the soil. Termites also help to make air available to the soil by means of the tunnels they dig.

The Ladybird Beetle

The beetles form a group of insects (called *Coleoptera*) which are readily identified by the fact that the fore-wings are modified into stiff coverings called *elytra* which meet in a straight line down the back of the body. The hind-wings, on the other hand, are membranous and usually folded beneath the elytra. The mouth-parts are modified for biting. Examples include the weevil, the fire-fly, the rhinoceros beetle, and the ladybird. The Coleoptera form the biggest group of insects, with about a quarter of a million species. The ladybird will serve as a good example of this group.

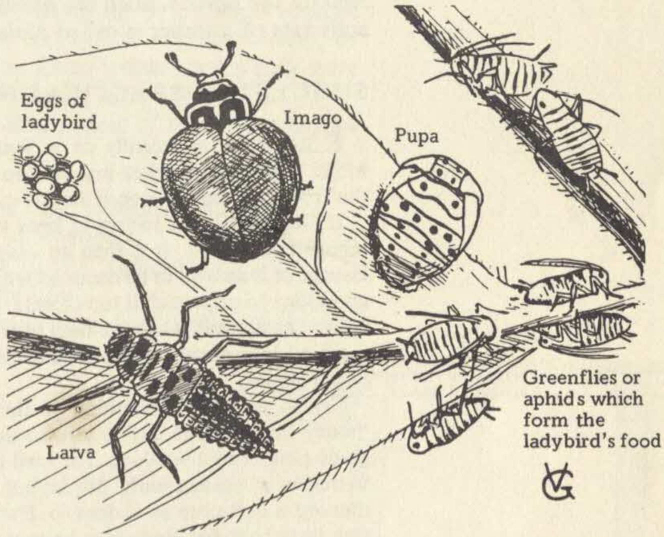


Fig. 10.9. Stages in the life-history of ladybird beetle

The ladybird (Fig. 10.9) is a small beetle with a rounded body whose elytra are spotted bright red and black. The hind-wings are membranous and when not in use are folded up in a complicated manner and hidden under the elytra. The first segment of the thorax is particularly large and has a joint which makes it movable. The mouth-parts are adapted for biting.

Mode of Life. The ladybird is carnivorous and feeds on various kinds of aphids. It is therefore found under leaves of plants which are frequented by aphids. It shows a warning coloration by means of the bright red and black colour of the elytra. This bright colour warns its enemies that it has an unpleasant taste. It has another method of self-preservation. This is by 'shamming death'—that is, pretending to be dead in order to escape further attack from a more powerful enemy. For example, if a bird pecks at it, the ladybird will fold up its legs, drop to the ground, and remain motionless until the bird departs.

Life-history. After mating, the female lays a large number of yellow eggs in small clusters under the leaves of a plant bearing aphids. The eggs hatch in a few days into larvae which have elongated bodies and three pairs of well-developed true legs. The body looks rather scaly behind the segments bearing the legs. The larvae feed voraciously on the aphids by means of their powerful biting jaws. The larva undergoes a number of moults and later changes into the pupa. The pupa has a rather rounded body much like that of the adult and, like it, is coloured red and black. In a few days' time the pupa moults and becomes an adult.

Economic Importance. Ladybirds are useful to us since they feed on pests such as aphids which cause a great deal of damage to our crop plants. Ladybirds have in fact been employed on a large scale to combat aphids when the latter threatened the yield of large farms. In this case they were purposely bred and sent to the infected farms and allowed to feed on the aphids. Such use of one organism to combat the destructive activities of another is called *biological control.*

SUGGESTED PRACTICAL WORK

1. Look for a greenfly on a young branch of an orange or lime tree. Make note of any other insects you may have studied which are found on the tree, and examine their relationship with the greenflies.

2. Occasionally a swarm of bees will settle on the branch of a tree in the school compound. It is then an easy matter to observe the activities of the insects. It is as well to be cautious when investigating a bee-hive and it is not a good idea to approach it too closely. Search for dead bees on the ground near a hive (preferably when the bees of the hive are not very active), and examine the hind-legs of the insects in detail, noting the structure of the pollen-basket in particular.

Try to discover something of the activities of the small bird called the 'honey guide'. This bird is said to act as though it is purposefully trying to guide people to a bee-hive. The bird may attract attention by flying from tree to tree in a zig-zag path, displaying the white flash of its tail-feathers and making a call-note as it does so. Eventually the bird remains stationary on a tree near to a bee-hive. It is known that the honey guide bird eats beeswax, and it may be that by leading a man to a bee-hive, the bird obtains the wax left by the honey-plundering actions of the man.

3. Break a termite mound, collect some of the individual termites, and try to identify the class or caste to which each one belongs. If you dig very carefully and thoroughly you may discover the chamber containing the queen termite (it is a good plan to seek the advice and help of the person in charge of termite extermination at the local Public Health Department or Public Works Department). Examine the queen termite and note the relative size of her head, thorax, and abdomen.

CHAPTER ELEVEN

Introduction to Animals with Backbones: Fishes

ALL the animals we have studied so far in this book are animals that have no internal skeleton. They are mostly soft-bodied and where the body seems hard this is due to an external skeleton (an exoskeleton) such as the chitinous shell of a crab or the chalky shell of a snail. Now, the rest of the animals we shall have to deal with are different in this respect. They have their skeletons inside their bodies; such an internal skeleton is called an *endoskeleton*. The major part of this endoskeleton forms the central axis which we call the backbone, or *vertebral column*. Thus these animals can be referred to as *animals with backbones*, or simply *vertebrates*, while those we have already described which have an exoskeleton are *animals without backbones*, or *invertebrates*.

Animals with backbones, or vertebrates, consist of five major groups or classes:

(*a*) *Fishes:* such as the shark, *Tilapia*, and millions fish.
(*b*) *Amphibians:* such as toads and salamanders.
(*c*) *Reptiles:* such as lizards, snakes, turtles, and crocodiles.
(*d*) *Birds:* such as the swallow or the hen.
(*e*) *Mammals:* such as rabbits, guinea-pigs, dogs, sheep, monkeys, and man.

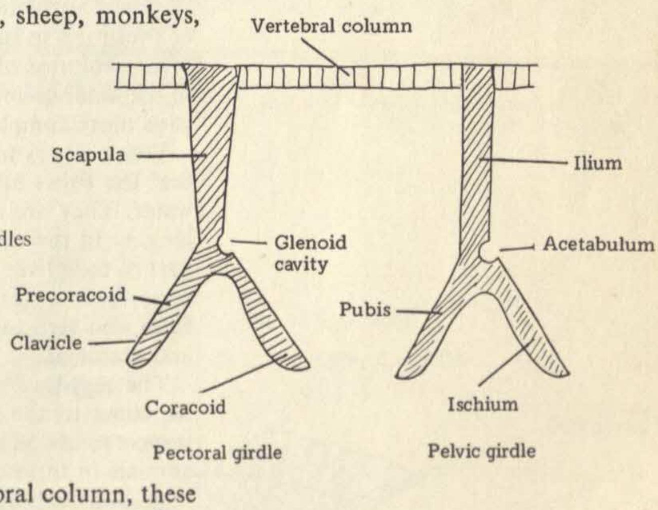


Fig. 11.1. Vertebral column and girdles

It should be emphasized that apart from the vertebral column, these higher animals have certain other characteristics in common. Before mentioning these we should make a few more comments about the vertebral column and the endoskeleton as a whole. The endoskeleton is jointed; the joints separate the small bones which make up the column. These small bones are called *vertebrae* so that the name 'vertebral column' means a column of vertebrae. Paired *girdles* are also associated with the vertebral column (Fig. 11.1).

One other feature common to the vertebrates is that the central nervous system is always well developed, with a single hollow nerve-cord (*spinal cord*) lying within the vertebral column. The front part of this is enlarged to form a brain. For the protection of the brain and other organs of special sense associated with it, the front part of the vertebral column develops a skeletal structure, the skull, or *cranium*.

Vertebrates also have gill-slits in the wall of the pharynx at some stage during their life. In this connection, the respiratory system always includes a suitable surface in relation to the pharynx. This is in the form of gills in those vertebrates (like fishes) which live mainly in water, and of lungs in those that live on land.

Lastly we may mention that the vertebrates have highly developed excretory organs in the form of true kidneys; they also have compact reproductive organs.

Evolutionary Trends. It is easy to see that the vertebrates deserve to be called 'higher animals' because, compared with the invertebrates, they have highly developed and specialized organs for carrying out the functions of life. The invertebrates are thus referred to as 'lower animals', while the vertebrates are 'higher animals'.

Throughout our discussion of the 'lower animals' we often drew attention to the slight advancements in any organism over any previously described. A similar approach will be made with regard to the treatment of examples of vertebrates. Here we may point out that the five classes of vertebrates mentioned above form a useful basis for the study of evolution in the vertebrates. For example, there is a general theory in the evolution of organisms that life started in the water and progressed to the land, quite apart from the theory that more advanced organisms have more complex structure.

When we try to illustrate this with the classes of vertebrates, we find that the fishes are the most primitive since they live all their lives in water. They are also much simpler in structure than the animals belonging to the other four classes. Then come the amphibia, which live part of their lives in water, or very moist conditions, and part under dry conditions on land. In addition, they are obviously more elaborate in form and structure than the fishes, but less so than the reptiles, birds, and mammals.

The reptiles follow next, with birds coming after them, and finally we come to the mammals which are the most successful of all with respect to life on the dry land. For example, the body temperature in the animals in three of the five classes changes according to the surroundings, and such animals are said to be *cold-blooded*, but the mammals and birds are animals in which the temperature of the blood is kept relatively constant, whatever the temperature of the surroundings, and they are said to be *warm-blooded*. This feature is obviously more useful on land where temperatures change to a greater extent than in water. In the development of one or two structures such as the lungs, the birds have been more successful, but on the whole mammals are at the peak of one of the major trends of evolution.

Fishes

Fishes are vertebrates that live all their lives in water. It is therefore expected that their structure, habits, and life-history will be suitable for life in water. They have paired and unpaired *fins* which are strengthened by a skeleton of rods called *fin-rays*. The skin is often covered with *scales*. Fishes breathe by means of *gills*.

There are two main groups of fishes. One group consists of all fishes with a skeleton made of a soft and gristly material called *cartilage*; hence they are called *cartilaginous fishes*. Examples are the dog-fish, sharks (the largest of all fish), skates, and rays. These fishes are regarded as primitive, or not so advanced as the other group. The other group consists of all fishes whose skeleton is made of bone; they are thus called *bony fishes*. Examples are the herring, sardine, cod, *Tilapia*, perch, millions fish (or guppies or top-minnow). The last two examples are small fish that are convenient for study since they can easily be kept in an aquarium in the school. We shall therefore use them to illustrate the structure, habits, and life-history of fishes as a whole. But since both of them are bony fishes we shall point out where necessary any differences between them and the cartilaginous fishes.

Millions fish (Fig. 11.2) is the name given in the tropics to the small fishes that are often found in shoals. They feed on mosquito larvae and have thus been introduced into streams, swamps, and village ponds throughout tropical countries for the control of mosquito larvae. *Tilapia* (Fig. 11.3) is also a fresh-water fish found in rivers and lakes in many parts of Africa. When *Tilapia* fishes are found along the coast they live in the brackish water of estuaries and lagoons. Unlike the millions fish, *Tilapia* feeds mainly on vegetable matter, which may be soft leaves that fall into the water, or weeds growing in it. *Tilapia* also lives on various types of green algae and plankton, which are tiny organisms that flourish in tropical water.

Fig. 11.2. Millions fish

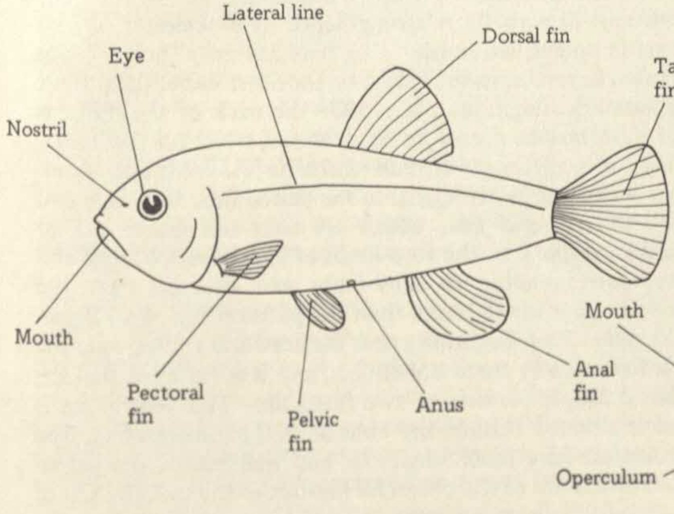


Fig. 11.3. *Tilapia*

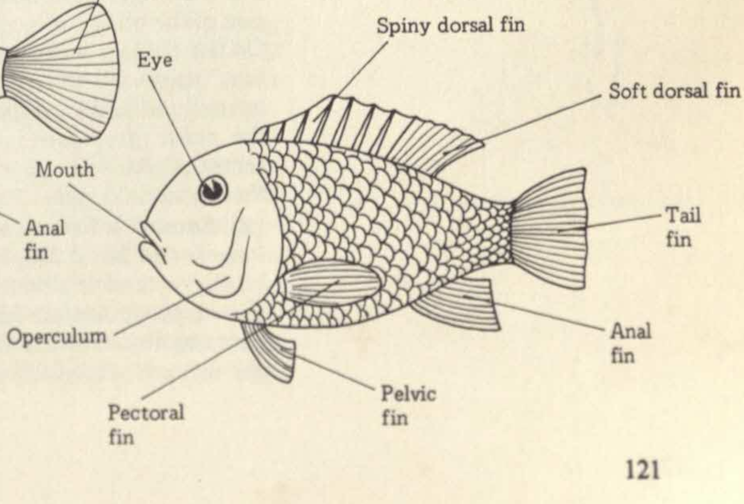
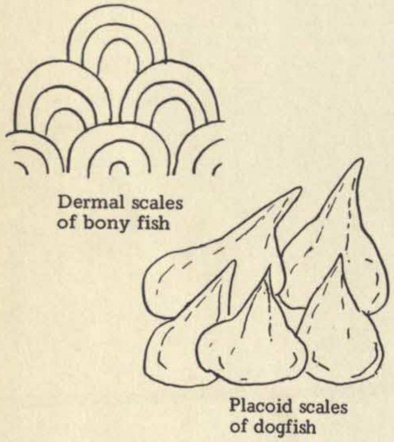


Fig. 11.4. Scales of a bony and a cartilaginous fish



Shape. The shape of the body of a fish is adapted for life in water. Thus the bodies of the millions fish and *Tilapia* are streamlined in shape, with no neck, so that the head readily merges into the trunk and tail. This sort of shape can move through a liquid like water with very little disturbance to impede its progress.

External Features. The body of the millions fish or of *Tilapia* is covered with *scales*. The *head* extends from the tip of the snout to the back of the *gill-cover*, then follows the *trunk* which ends at the *anus*, and the rest of the body is known as the *tail*. The mouth is large, with jaws which bear sharp teeth.

Above the mouth are two holes or *nostrils* which communicate with olfactory organs. On either side of the head is an eye; these have no eyelids, and behind each of them is a gill-cover, or *operculum*, with the gills underneath. There is a *dorsal fin* on the back of the body, a *caudal fin* at the end of the tail, and an *anal fin* below the tail. Apart from these median fins there are the paired *pectoral fins* behind the gill-cover and the paired *pelvic fins* near and below the pectoral fins.

Scales. The bodies of the millions fish and *Tilapia*, like those of all bony fishes, have a covering of scales which overlap each other with their free ends directed backwards. This arrangement of the scales allows the water to flow easily, thus aiding the movement of the fish. The slimy skin which covers the individual scales also helps water flow, besides making the scales waterproof. The scales protect the fish. On them are concentric rings which, in temperate waters where there are well-defined seasons, indicate the age of the fish. Since clearly distinct seasons do not exist in the tropics, these rings can rarely be used to indicate the age of the fish. In cartilaginous fish the scales are rather tooth-like, spiny, and stronger (Fig.11.4).

Fins. As mentioned above, a fish has two types of fins, the median unpaired fins and the paired fins. The latter correspond to the limbs of the higher vertebrates such as frogs, birds, and mammals. In the bony fishes the front part of each fin is strengthened by a skeleton of rods termed fin-rays, or spines, while the other part has only thorny fibres and is rather soft. (In cartilaginous fishes, on the other hand, the fins are supported by small cartilaginous plates.) On the back of the millions fish is a rather short *median dorsal fin* near the tail, while on the underside of the body is a much longer *median ventral fin* just behind the anus. On the tail is a *caudal fin*. With regard to the paired fins, there are two sets; these are the *pectoral fins*, which are near the gill-cover, or operculum, and correspond to the fore-limbs of higher vertebrates, and the *pelvic fins*, corresponding to hind-limbs and situated near the centre of the body on a lower plane than the pectoral fins. In *Tilapia*, the dorsal fin is rather long, beginning near the head and ending near the tail. Some fish have two or three dorsal fins, and it is believed that the long dorsal fin of *Tilapia* consists of two fused fins. The ventral fin is no bigger and is situated behind the anus as in the millions fish. The paired pelvic fins are here much closer to, and well below, the paired pectoral fins. With the aid of the powerful muscles of the tail, the fins of the fish are responsible for movement and balance in water.

Movement. Fishes move in the water by swimming. The tail-muscles and other muscles of the trunk contract alternately on the two sides and thus cause a wave-like movement of the tail and the tail-fin (Fig. 11.5). This action of the tail and its fin is like that of a man at the stern of a boat holding one paddle which he moves from one side of the boat to the other, and it supplies the main driving force which pushes the fish forward in a straight line. For rapid movement the paired fins are folded close to the body. The other fins of the fish help mainly in balancing and changing direction and can be moved independently. Thus, when the fish hovers in the water the pectoral fins are spread to balance the body. For very slow movements the paired fins may be used as paddles, and in this case the tail is kept still. The median dorsal and ventral fins behave like the keel of a ship in stabilizing and keeping the course of the fish straight. The swimming process of the fish is also aided by water flowing out from the gill-chambers during breathing.

We have already mentioned the advantage of the shape of the fish in swimming. Man builds boats and aeroplanes which copy the shape of the fish; we can see, for example, that they are streamlined and the surface is made very smooth. In fishes there are many glands in the epidermis which secrete mucus to keep the surface smooth and thus reduce friction during movement. To sum up it could be said that the tail provides a propulsive force, the caudal, or tail, fin is used as a rudder in steering, the median fins are stabilizers while the paired fins alter the swimming level, and also help in balancing.

The Swim-bladder. While on the topic of movement we may mention the *swim-bladder*, which is a long, narrow tube found under the backbone in bony fishes. It contains gases, the quantity of which is altered to adjust the specific gravity of the fish to water pressure at different depths. We sometimes see freshly caught fish with their stomachs hanging out of their mouths. This is caused by the pressure on the swim-bladder suddenly being reduced as the fish is pulled from a great depth to the surface. Consequently, the swim-bladder expands or bursts, forcing the fish's viscera out of its mouth.

The gas in the swim-bladder contains a large amount of oxygen which is used during difficult conditions, as when oxygen is in short supply. For example, when *Tilapia* is placed in stagnant water, the oxygen in the swim-bladder is absorbed for respiration and in its place is found nitrogen and carbon dioxide.

The Lateral Line. In both the millions fish and *Tilapia* there is a long, well-marked line, called the *lateral line*, on both sides of the body. It marks the position of a canal under the skin, whose function is to detect differences in pressure and vibrations in the water. It is thus a sensory organ.

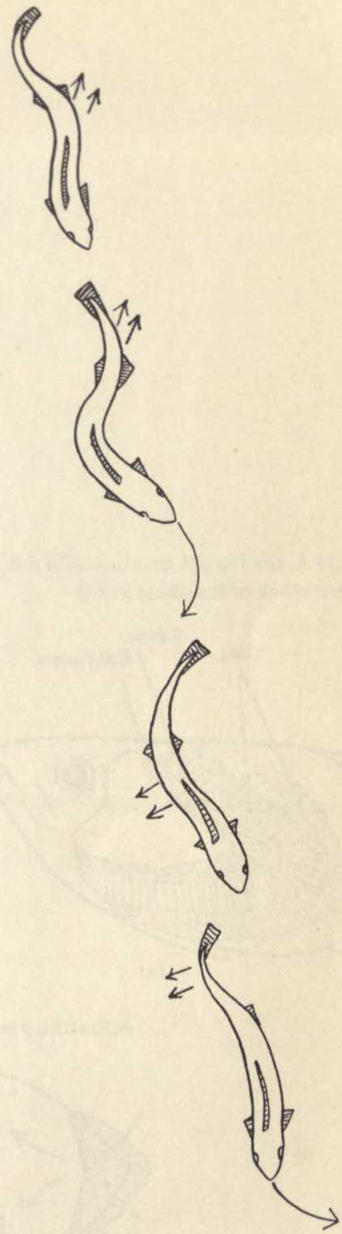


Fig. 11.5. Mode of movement of fish

Colour of the Body. The colour of the fish is itself adapted to its environment. Typically, the lower surface and side is silvery-white, while the upper part is of a darker colour. These colours have a protective function against the enemies of the fish. Thus when light falls on the surface of the water the lower silvery-white colour of the fish makes it appear invisible to its enemies when they are swimming below. The deeper blue colour of the water when viewed from above also agrees with the darker colour on the upper part of the fish, so that it is protected

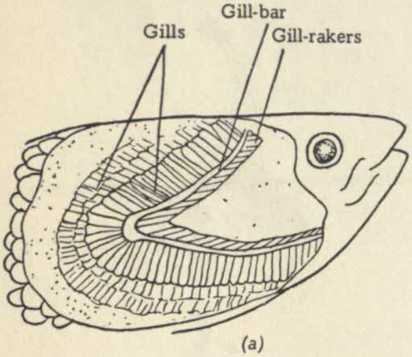
from us when fishing. Thus the colours of the fish furnish a good example of *protective coloration*. The millions fish and *Tilapia*, both of which live in water with weeds, have a further method of protective coloration. They have on their flanks stripes which serve to break the outline of the fish and thus make them difficult to see against the swaying weeds.

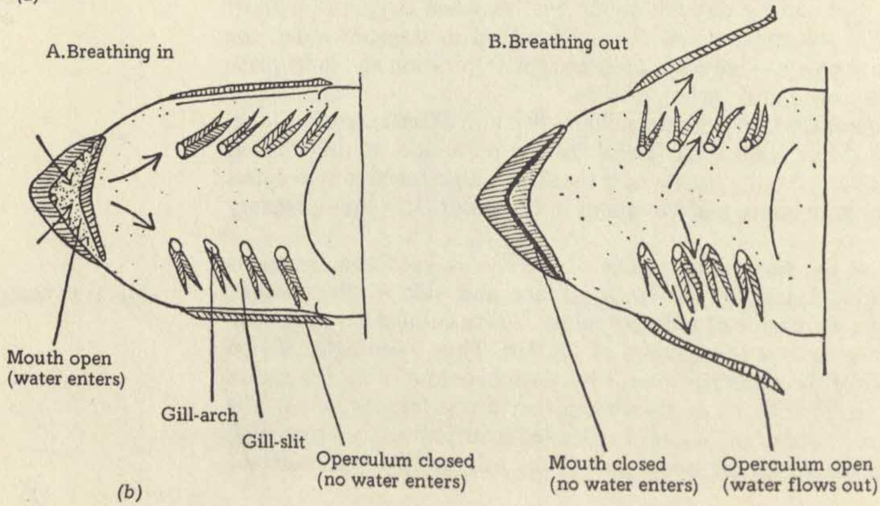
Gill-covers and Respiration. The gill-cover, or operculum, is the large flap with free lower and posterior edges on either side of the head. (There is no gill-cover in cartilaginous fishes.) Under the gill-covers are found the gills, which are usually four in number. The gills, which provide a large surface for respiration (Fig. 11.6), are separated by five *gill-slits* in the wall of the pharynx. The gills are the principal structures for respiration, or breathing. Each gill consists of a double row of slender *gill-filaments*, which are pink in colour because they contain blood-capillaries. Each double row of gill-filaments arises from a cartilaginous gill-arch. The latter bears on its inner side small rods of bone known as *gill-rakers* which protect the delicate gills against particles of food and other materials that may wander between them. These particles are then swallowed as food.

When the bony fish breathes (Fig. 11.6), it first of all opens its mouth and closes the gill-covers against the body. The gill-arches expand and water then flows into the mouth. To get the water to proceed over the gills, the mouth is closed, and the gill-covers are opened. The gill-arches then contract and the water already in the mouth flows over the filaments and out through the gill-covers. As the water passes over the gill-filaments, respiration takes place—that is, oxygen in the water enters the blood in the gill-capillaries while carbon dioxide leaves them and diffuses into the water.

Habits. Fresh-water fishes like the millions fish and *Tilapia* appear to be active both by day and by night. They habitually swim against the current as this aids respiration and the capture of food. When food enters the mouth conical teeth are used to hold but not to chew it. Millions fish and *Tilapia* may live together in large numbers but they can also lead a solitary life. With their large eyes, which are lidless and

Fig. 11.6. (*a*) The gill structure of a fish; (*b*) procedure of breathing in fish





which have only a transparent covering, these fishes can see clearly about them, an advantage when escaping from their enemies. They smell by means of the *olfactory organs* which appear as a pair of holes above the snout.

Migration. In a large lake or stream these fresh-water fishes travel in a group, or *migrate*, usually for the purpose of breeding, from deeper to shallower and faster water. They may also migrate downstream into deeper water when the rains are over and the dry season begins, and retrace their steps when the rainy period returns.

On the other hand, sea fishes such as herrings and salmon migrate great distances.

Life-history. Reproduction in most fishes is carried out by the male and female shedding their spermatozoa and ova respectively into the water where fertilization soon takes place. As mentioned above, this is carried out in the spawning grounds in shallow water, and the fishes disperse after spawning, leaving the fertilized eggs to develop by themselves. The millions fish, like other bony fishes, behaves in this way but *Tilapia* is rather different, for it shows a certain amount of parental care or concern for the future of its eggs. Thus, in the common type of *Tilapia* the female carries the fertilized eggs in her mouth for the two-week hatching period, during which time she does not eat. When the eggs hatch into young fishes, these do not disperse but stay near the mother; when there is danger she allows them to enter her mouth again for protection. In another type of *Tilapia* it is the male that broods and protects the eggs in his mouth in this way. The parental care ceases when the young fishes are about half an inch long, and they then disperse.

Because of the care given by the parents of *Tilapia*, a higher proportion of their young survive than in most other fishes, which give no such care. For this reason the female *Tilapia* lays only about a thousand eggs while other fishes may lay many times this number. For example, a herring can lay over forty million eggs. The young fish readily fall prey to other bigger fish, including their own parents, crabs, or sea birds, and only very few remain as survivors to replace their parents and produce the next generation.

SUGGESTED PRACTICAL WORK

1. Identify the parts of the fish you are given to examine in class. In what ways does this fish differ from the description of *Tilapia* or millions fish given in the text?

2. Watch the movement of some small fishes in an aquarium. What do the fishes feed on?

3. In setting up an aquarium it is essential to introduce green plants. Of what benefit are such aquatic plants to the fish and other animals in the aquarium?

4. Visit a local market and observe the fish on sale. Try to obtain a live specimen of the catfish (*Silurus*) or some other unusual fish and record the unusual features of this animal.

5. One of the most interesting African fish is the African lungfish (*Protopterus*). It lives in fresh water (that is, in rivers and streams and not in the sea). This remarkable fish can live in a mud 'cocoon' as well as in water, and you should try to discover as much as possible about its internal structure.

CHAPTER TWELVE

Amphibians

AMPHIBIANS form a class of vertebrates which spend the first part of their lives in water and the second part on land. During the first part, when they are called *larvae*, they live in water like fishes and even breathe by gills. During the second, adult, stage they live on land as reptiles or mammals do, and breathe by means of lungs. The adult amphibian has a soft body without any external covering or exoskeleton. The life-history of amphibians illustrates an important transition in the evolution of the vertebrates from water to the land. For example, the adult frog has proper limbs (not fins, as in the fishes) which are built on the same *pentadactyl* or five-fingered plan as in the higher vertebrates such as reptiles, birds, and mammals (see Fig. 15.7).

Examples of amphibians are the toads and frogs which have no tails, and the newts and salamanders, which have tails. In the tropics, toads are commoner than frogs, which live mainly in temperate climates. In Africa, the common toad is *Bufo regularis*, while in the islands of the West Indies the common type is the Surinam or marine toad (or crapaud) named *Bufo marinus*. These have very similar structure and habits, and will serve to illustrate the adaptation of toads to their environments.

The Toad

Toads, like the marine toad of the West Indies and the common African toad, are most noticeable during the rainy weather when they come out at night in large numbers. They disturb us a great deal with the loud noise they make while feeding and laying eggs. During the day, particularly in the dry periods of the year, they hide in small holes in the ground, in tree trunks and under stones, and in dense vegetation where they are protected from the sun. They feed largely on worms and insects, especially cockroaches.

Shape of the Body. (Fig. 12.1.) The body is short and fat when seen from above and appears oval in shape. The head is joined to the rest of the body without a neck, and there is no tail. Thus the body consists only of the head and trunk. There are no fins as in fishes, but instead there are two pairs of jointed limbs, of which the front ones are short and the hind ones long and powerful.

The shape of the toad can be said to be adapted for life both in water and on land. For life in water we find that, as with fish, the body is streamlined. There is no neck and no sharp distinction between head and trunk. The absence of a tail also facilitates hopping on the ground.

Covering or Skin. The skin of the toad has no scales or any other exoskeleton. On it are warty lumps which show the positions of small *poison-glands*. On each side, just behind the head, are found larger poison-glands. In some toads, like the marine toad, some of these warty lumps lead to *mucus-secreting glands* while others contain pigment-cells.

The presence of mucus-secreting glands in the skin of such toads as the marine toad provides a useful adaptation. For not only does the skin of the toad protect its body, but it also functions as an additional respiratory surface. It therefore needs to be kept moist on dry land and this is done by the mucus-secreting glands. They also make the surface slippery and so help the toad in escaping from its enemies. The poison-glands also serve to protect the toad from animals such as dogs and cats. If a dog or a cat picks up a toad in its mouth, it will quickly drop it, owing to the distasteful substance produced by the glands. Because of this, it has often been believed that the toad is very poisonous and even that snakes obtain their poison from toads! This is quite wrong. The substance secreted by the so-called poison-glands is distasteful but not harmful. Consequently there is no need to be alarmed if it gets on your hands.

The toad is dark brown above and paler below, with irregular dark patches. The uneven pattern so produced gives protective colouring or camouflage to the toad. This is made still more effective by the fact that its pigment cells, by expanding or contracting, can bring about considerable changes in the basic colour of the toad.

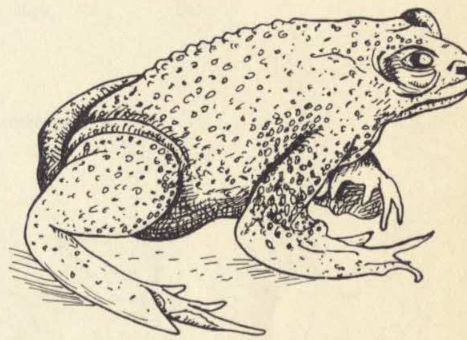


Fig. 12.1. External features of toad

The Head. The head of the toad is blunt, slightly pointed, and flattened. The mouth is wide and situated at the very end of the head; there is no obvious snout. There are no teeth inside the mouth, so that the toad is unable to chew. Attached to the front of the lower jaw is the tongue, which it can shoot out in an instant to catch the insects on which it feeds. Above the mouth are two external nostrils. The eyes, which are very mobile, are raised almost on the top of the head, thus enabling the toad to look around and to see above the water when it is swimming. This is necessary, since the toad has no neck to turn round when it wants to observe its surroundings. The eyes have eyelids, although their function is largely carried out by a transparent fold which is drawn over the eyeball from below. We found that the fish have no eyelids, but for life on the land eyelids become necessary. On either side of the head, behind the eye, is a circular patch of skin called the *ear-drum*, which is part of the ear. However, there is no external ear such as we shall find in the case of mammals. Below the head the flesh of the throat is particularly soft and moves up and down during breathing.

Limbs and Movement. (See Fig. 12.1.) In water, the adult toad is able to swim and, as we have seen, is streamlined. In addition there are webs of skin between the toes which enable the legs to be used as oars in swimming. The web is better developed in toads which do much swimming, such as the marine toad, but is reduced to tiny structures at only the bases of the toes in those toads such as the common African toad, which only occasionally go into the water.

On land the toad travels by hopping and the limbs are well adapted for this purpose. For lifting the body off the ground in order to leap, the hind-limbs play the major role. They are much longer than the fore-limbs and are folded when at rest, so that when they are quickly straightened the body is easily raised from the ground. Each hind-limb consists of three parts, the thigh, the leg, and the foot, the latter being rather elongated and having five toes. For taking the shock as the toad returns to the ground after leaping, the fore-limbs are also well adapted,

for they are short and thick. Each fore-limb consists of the upper arm, forearm, and the hand; the latter has only four fingers, the thumb being missing.

Habits. As mentioned already, toads are nocturnal in habit and come out at night to catch worms and insects to feed on. To catch its prey, the toad suddenly shoots out its tongue at the insect. Since the free end of the tongue is sticky, the prey is captured and brought into the mouth.

As already mentioned, the toad has no teeth and so cannot bite. However, it has other ways of protecting itself from its enemies. One method, which has already been dealt with, is to secrete distasteful fluid from its skin. Another way is to fill its lungs with air and thus swell its body immensely. This makes it seem much larger than it really is and frightens its smaller enemies. Yet another method consists in squirting water from a reservoir at its attacker. The reservoir is called the *allantoic bladder*, and is situated above an aperture called the *cloaca* situated at the end of the trunk.

Life-history. (Fig. 12.2.) In rainy weather, toads come out in large numbers to breed. The males make the familiar croaking noises which attract the females to them. As the female, whose body is swollen with eggs, approaches the male, he mounts on her back and clings firmly to her by means of thickened pads, called *marriage-pads*, which develop in his palms during the breeding season. The female carries the male until she lays her eggs, which are in a string, into the water when at the same time the male sheds his sperms over them so as to fertilize them in the water. The eggs are small and fairly numerous, and each of them is surrounded by jelly. This jelly serves a number of useful functions. It protects the eggs from bacteria and injury and discourages attack by water-fleas and water-birds. It also provides a buffer for the eggs and, by swelling, separates one egg from the other and thus gives them room to develop, as well as enabling oxygen to enter the whole surface of each egg. The eggs float on the surface of the water.

Owing to the high temperature, development of the eggs is fairly rapid in the tropics. This is in contrast to the slow development of frogs' spawn in temperate regions. At first, each egg is black on the upper surface and yellowish white with yolk below, but a few hours after fertilization the upper surface grows over the yellowish portion and the egg becomes black all over. By the end of two days the eggs have elongated into embryos within the jelly. These embryos are the tiny curved tadpoles (Fig. 12.2) which wriggle out of the jelly by the end of the second day, and attach themselves to weeds in the water. At first the tadpole has only a head, body, and tail. There is a horseshoe-shaped *sucker* beneath the mouth by which it attaches itself to weeds, while the future positions of eyes, ears, and nostrils are marked by pits.

Within the next three days, the *external gills* develop as projections on either side of the head. These gills, which look like feathers, are the organs for breathing. Oxygen dissolved in the water is absorbed by the blood in the gills as the water flows over them. The external gills do not last long, but wither and have disappeared by the fourth day, when they are replaced by *internal gills* with four gill-slits like those of the fish. At the end of a week the mouth, anus, and eyes have developed. The anus is

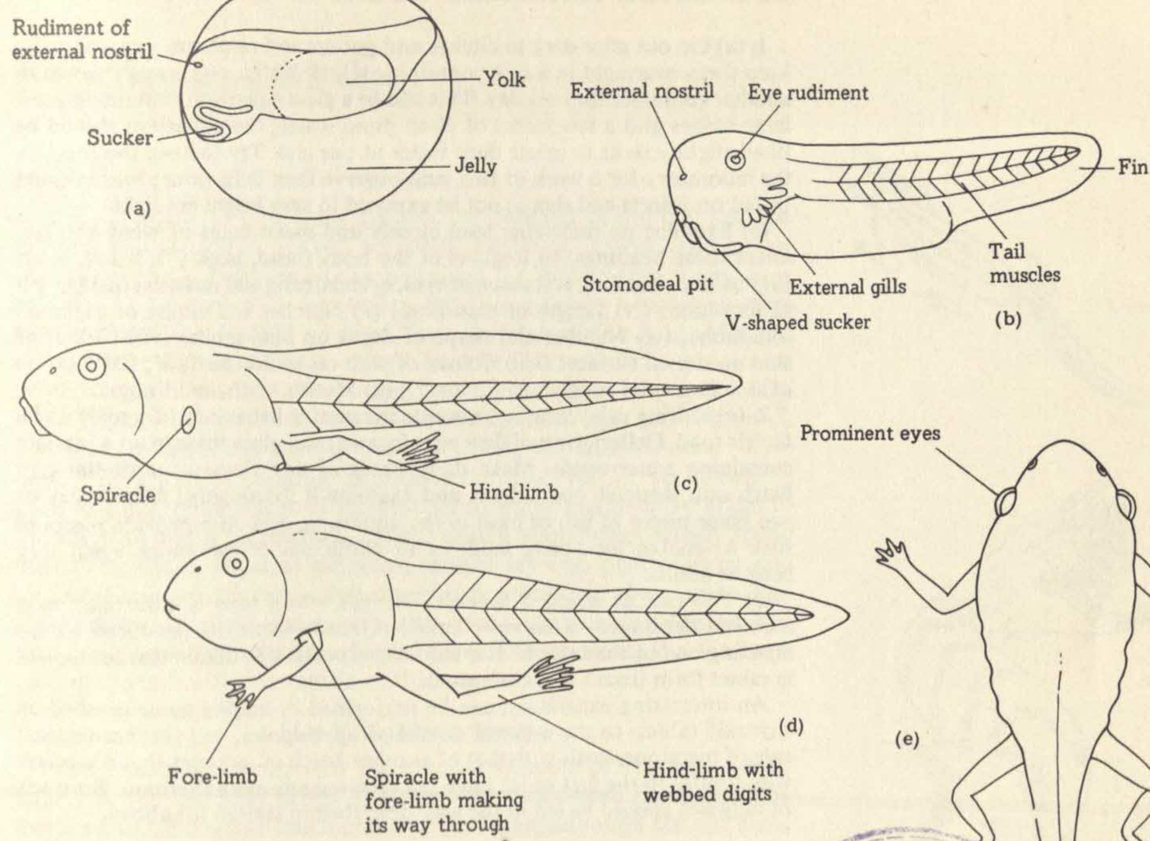


Fig. 12.2. Life-history of toad: (*a*) developing egg; (*b*) tadpole with gills; (*c*) hind-legs have appeared; (*d*) fore-legs have appeared; (*e*) gradual disappearance of tail; (*f*) young toad on land

situated at the base of the flattened tail; with the aid of a lens it is possible to see the backbone through the tail. Throughout this period the tadpole is a vegetarian and has a long, coiled intestine (see Fig. 12.2) which can be seen within its body. Later a flap, which is the gill-cover, or operculum, grows to cover the gill-slits, just like the gill-cover of a bony fish. The method of breathing is then very much like that of a fish.

By the end of a month, the hind-limbs start to appear, followed by the fore-limbs. The tadpole now feeds actively and grows rapidly. It changes to a carnivorous mode of feeding, and the intestine becomes shorter, as is typical of carnivorous animals. The internal gills also begin to wither away, to be replaced by the growth of the lungs. The tadpole is now able to come to the surface of the water to breathe ordinary air. Later the tail begins to be absorbed and the creature, now a toad, leaves the water for land. In this way the metamorphosis of the larva into the adult toad is completed.

SUGGESTED PRACTICAL WORK

1. (*a*) Go out after dark to ditches and gutters and catch one or two toads; keep them overnight in a sink containing a little water, and transfer them to another container the next day. This can be a glass aquarium containing some large stones and a few inches of clean pond water; the aquarium should be tilted slightly so as to create deep water at one end. Try to keep the toads in the laboratory for a week or two, and observe their behaviour; toads should be fed on insects and should not be exposed to very bright sunlight.

(*b*) Examine an individual toad closely and make notes of what you see, under these headings: (i) Regions of the body (head, neck (?), trunk, etc.); (ii) Position, number, and shape of eyes, eyelids, ears, and nostrils; (iii) Length of fore-limb; (iv) Length of hind-limb; (v) Number and shape of digits on fore-limbs; (vi) Number and shape of digits on hind-limbs; (vii) Colour of skin on dorsal surface; (viii) Colour of skin on ventral surface; (ix) Texture of skin (smooth? rough? dry? moist?); (x) Mouth, teeth, and tongue.

2. (*a*) During rainy weather, observe the mating behaviour of a male and a female toad. Collect some of their eggs (spawn) and place these in an aquarium containing water-weeds. Make daily notes of any changes, until the eggs hatch out. Remove one tadpole and examine it thoroughly. After a day or two place pieces of fish or meat in the aquarium, and later provide pieces of stick to enable the young tadpoles to climb out of the water when they become adults.

(*b*) The rate at which a tadpole changes into a toad is controlled by a chemical substance—a *hormone* called *thyroxin*—which is produced by the *thyroid gland* of the tadpole. It is sometimes possible to obtain this compound in tablet form from a chemist's shop.

An interesting experiment can be performed by adding some crushed-up thyroxin tablets to the water of one batch of tadpoles, and comparing their rate of metamorphosis with that of another batch of tadpoles that are otherwise similar to the first which have not received any extra thyroxin. Both sets of tadpoles should be fed in the way described in section (*a*) above.

CHAPTER THIRTEEN

Reptiles and Birds

Reptiles

REPTILES form an important group of vertebrates in the tropics. The group includes lizards, snakes, tortoises, turtles, alligators, and crocodiles (Fig. 13.1). They are all characterized by the fact that the body is completely covered with dry scales, which constitute a more suitable external covering for life on land than the skin of the frog. Most of them, like other vertebrates except for the fishes, have two pairs of pentadactyl limbs with claws on the digits. Snakes have lost their limbs. Reptiles generally do not support their bodies but wriggle on the ground.

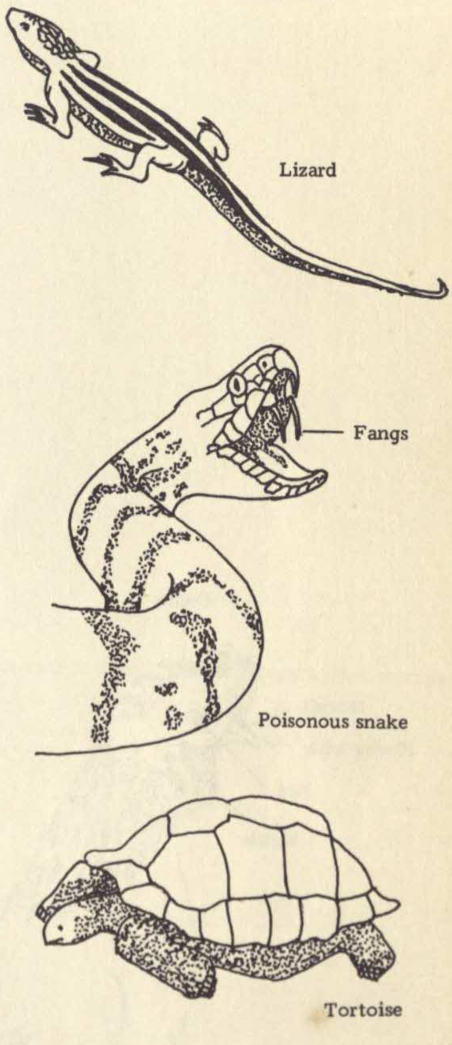
Evolution. Although the reptiles are among the cold-blooded vertebrates, they almost certainly represent the first type of vertebrate to have lost nearly all traces of adaptation to water and to have taken to life on land quite successfully. Thus, unlike amphibians which spend their early life in water as tadpoles, reptiles lay eggs protected by calcareous shells, which can be left on the dry ground till they hatch. The scales covering their bodies are also more suitable for life in dry situations, and the limbs are adapted for land movement. We shall not describe specifically any reptile in this course.

Birds (The House Fowl)

Birds are easily recognized by their possession of feathers which largely cover the body except the feet. They also have the fore-limbs modified to form *wings* which are used for flying, although certain birds cannot fly. The hind-limbs are covered with scales and are adapted for walking, perching, or swimming, and the feet are suitably modified for a particular mode of use.

Since the fore-limbs are adapted for flying and not for grasping or similar functions, the original role of the fore-limbs is assumed by the mouth. The latter is modified into a long horny beak without teeth, which serves various functions depending on the needs of particular species of bird.

The feathers of birds insulate their bodies and make it possible for the body temperature to be regulated as in mammals. Birds lay eggs protected in hard shells like those of reptiles, and show a high degree of care for their young.



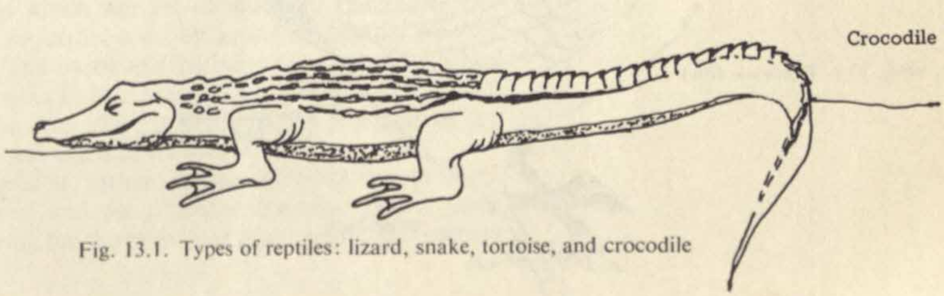


Fig. 13.1. Types of reptiles: lizard, snake, tortoise, and crocodile

Birds are perhaps the best-known group of animals, and are spread all over the world. Their beautiful colours and voices have attracted so much attention that both professional and amateur students have devoted time to the detailed study of birds through the hobby of 'bird-watching'.

Evolution. The characteristic features of birds, outlined above, enable us to see that there is some relationship between reptiles and birds. There are also obvious differences which show the significant advance of birds over reptiles, and indeed over all other animals except the mammals.

The similarities between reptiles and birds can be illustrated by three examples. In the first place, both have epidermal scales, which in the case of birds are found only on the legs. The scales and the feathers have the same origin, although the latter are more complex in structure. Secondly, although in general birds have no teeth, there is evidence from fossil remains that there once existed a bird, *Archaeopteryx*, which not only had teeth but also had certain characteristics common to both birds and reptiles. For example, this prehistoric bird had feathers, but there were also well-developed digits, bearing claws, on the wings. Finally, both birds and reptiles lay eggs which are covered with hard shells. These points provide evidence that birds must have evolved from reptiles in ancient times.

As to the significant evolutionary advance of birds over reptiles, we have the regulated body temperature resulting from the insulated covering of feathers. This feature, together with their ability to fly, their highly developed voice, hearing, and sight, and their special care for their young, make birds more successful in their adaptation for life on land and in the air.

The domestic (or house) fowl, or chicken, is a bird which can be used to illustrate the structure and life-history of birds in general, although it does not normally fly.

External Features. (Fig. 13.2.) The body of the fowl consists of the head, the neck, the trunk, and the tail. The head is usually relatively small, the neck rather long and flexible, and the trunk, or body, large and streamlined, while the tail is short and bears the tail-feathers. On each side of the body is a Z-shaped wing bearing long flight feathers.

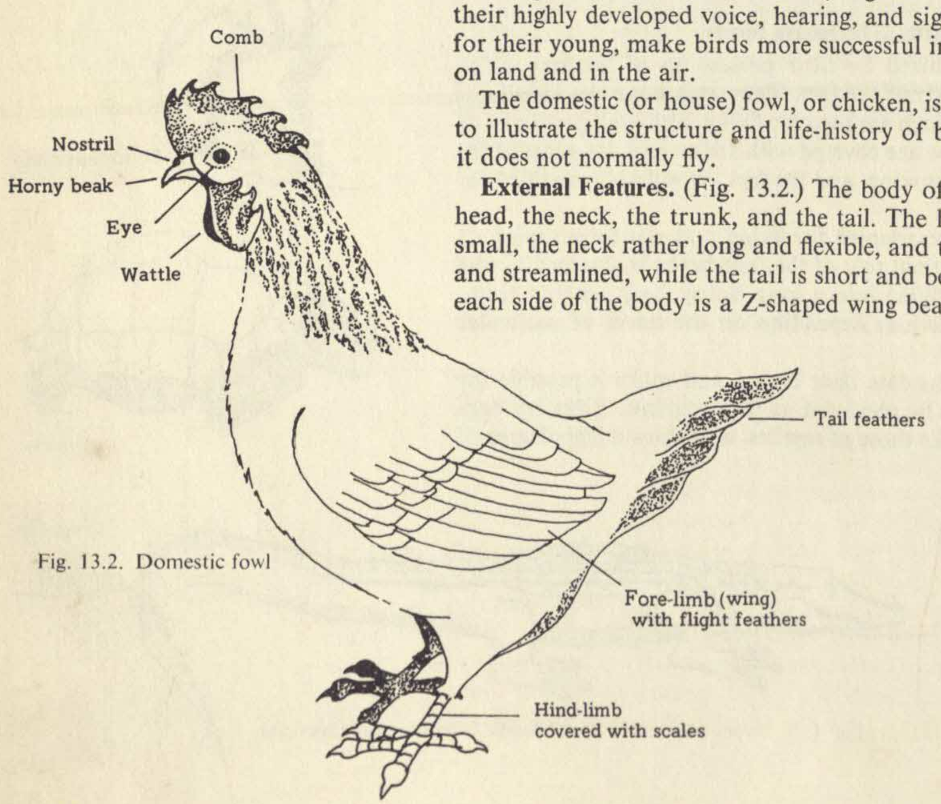


Fig. 13.2. Domestic fowl

The wing is a modified fore-limb and is extended when the fowl is flying. The body of the fowl is supported on the two hind-limbs. The upper segment of each hind-limb is muscular, but the lower leg is slender and without muscles; it is covered with scales and may also bear a cornified spur. Each foot has four toes with horny claws at the ends.

The head of the fowl bears the elongated beak or bill. On the upper part of the beak are two slits which are the nostrils. On each side of the head is a large eye with an eyelid divided into upper and lower halves. In addition to the eyelids, below the eye there is a membrane called the *nictitating membrane* which can be drawn over the eyeball. Behind each eye is an ear opening, covered by feathers. On the top of the head is the fleshy *comb* and below it may be the *wattles*. The skin of the fowl is soft and loosely attached to the muscles. It has only one gland, the *oil-gland*, on the tail.

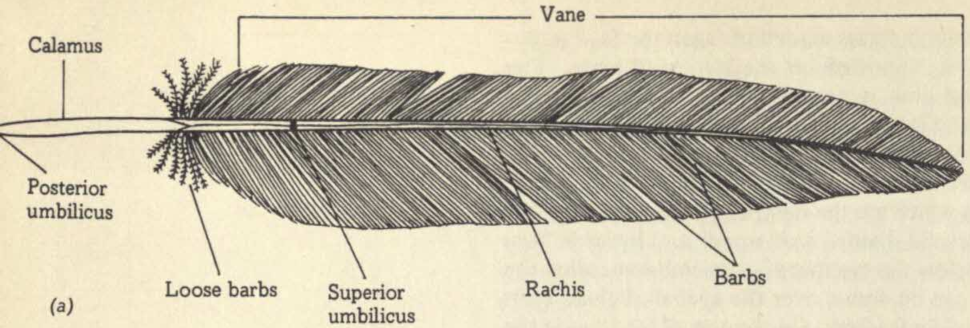
External Adaptations: Shape and Nature of Body. As mentioned above, the body of the fowl or other flying bird is streamlined, that is, the middle of the body is broadest and tapers towards either end, a shape which offers least resistance when moving through the air. In addition, the feathers not only overlap one another but are directed backwards, so that they are pressed into a smoother form as the wind passes over the body in the air. When the bird is flying the feet are either tucked close to the body or stretched out behind.

The body of most flying birds is relatively light, since the feathers increase its size without increasing its weight. But in birds like the ostrich, which do not fly at all, the body is heavy. The fowl, which flies only occasionally, is gradually losing the habit of flying as it is bred to produce more and more flesh.

The Feathers. The feathers are peculiar but interesting structures possessed only by birds. They have very useful qualities which fulfil important functions. As indicated, feathers are good insulators and help to regulate the temperature of the body. They are also waterproof, mainly as a result of oil which comes from the oil-gland situated on the tail. The bird dips its beak into the gland and spreads the oil on the feathers. Birds maintain their feathers in good condition by preening them with their beaks.

The structure of feathers is easily seen in a typical feather (Fig. 13.3) such as is found on the wing of the fowl. It has a central horny axis called the *shaft*, or *rachis*, at the base of which is the hollow *quill*. This gives the name of the quill feather to this type of feather. The shaft bears the 'feather proper' with its flat surface, called the *vane*. Each half of the vane is made up of many narrow and parallel rows of branches called the *barbs* which are set obliquely to the shaft. The barbs are held together on either side by a row of smaller hooked branches called *barbules*. The barbs and barbules are easily seen when the vane is disarranged by the finger. Many of the quill feathers have a secondary shaft called the *after-shaft* attached at the junction of the principal shaft and quill, and this has its own vane.

There are three main types of feather. These are the *contour*, or body, feathers, the *down* feathers, and the *filoplume* feathers. The contour feathers provide the covering for the main part of the body, and include



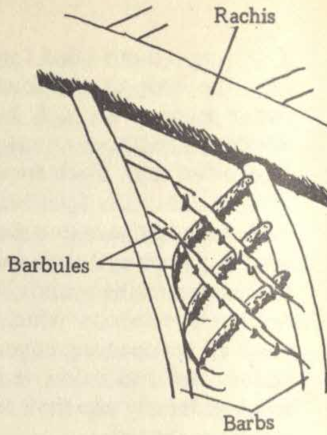
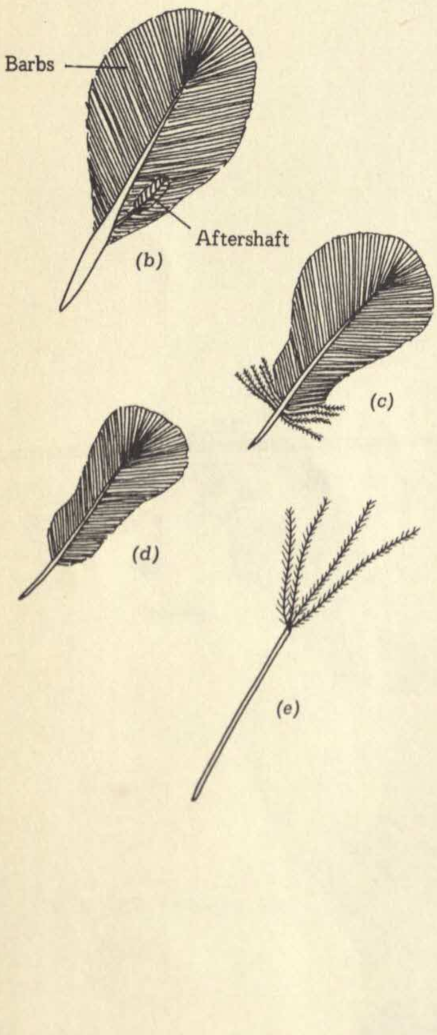


Fig. 13.3. Feathers of a bird: (*a*) quill feather; (*b*) contour feather; (*c*) down feather; (*d*) covert feather; (*e*) filoplume



the large flight or quill feathers of the wings and tail, just described as a typical feather. The shaft is nearly straight in these wing- and tail-feathers. In many other contour feathers, however, the shafts are curved so that their tips lie parallel to the surface of the body, thus overlapping one another and resulting in a smooth surface. Such contour feathers have rather slender shafts, while a number of the barbs at the lower part of the vane have no hooks to the barbules, so that they are free and soft.

The down feathers (Fig. 13.3) are found in between the contour feathers in adult birds, and form the main covering in young birds. They have a short shaft with long flexible barbs and short barbules, which are not hooked together. They provide extra warmth as they hold air between their loose barbs. They are also greasy, and in water-fowl, such as ducks, prevent the body from getting wet.

The filoplume feathers (Fig. 13.3) are minute, hair-like feathers which remain on the skin of the fowl after it has been plucked. They are distributed rather sparsely all over the body, with clusters of them at the base of some contour feathers. A filoplume consists of a thread-like shaft bearing a tuft of a few rather weak barbs and barbules at its tip. The function of the filoplume feather is not fully understood.

The Wing. (Fig. 13.4.) The wing of the common fowl provides an interesting modification of the pentadactyl, or five-fingered, limb. When it is compared with the human arm (see Fig. 15.7) it is possible to recognize most of the bones, although some of them are much reduced or fused together. For example, the three parts of the limb which correspond to the upper arm, fore-arm, and hand can be distinguished. The number of digits is reduced from five to only three; of these the thumb is readily seen as a separate digit, but the second and third digits are joined together and covered with a web of skin. The thumb bears a tuft of feathers called the *bastard wing*, while the hand and the fore-arm bear the large flight feathers of the wing. The quill feathers attached to the hand are called *primaries*, while those on the fore-arm are called *secondaries*.

When the bird is at rest, the wings are folded into the shape of the letter Z over the sides of the body, and in this position and shape they do not disturb the bird when it is walking or hopping. In flight the wing is extended but does not become straight, owing to two folds of skin

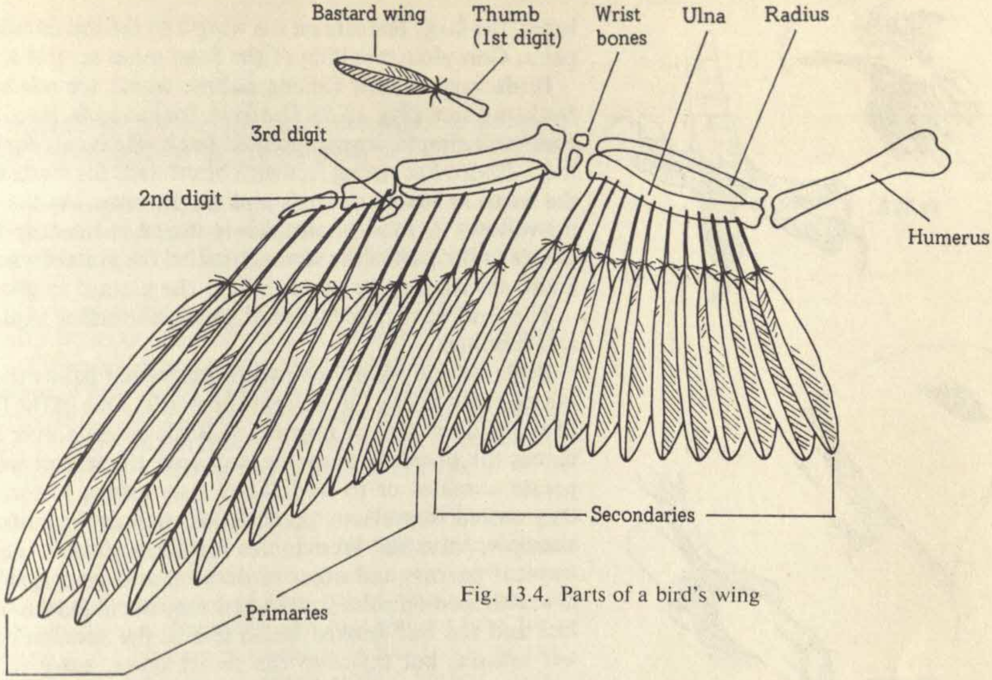


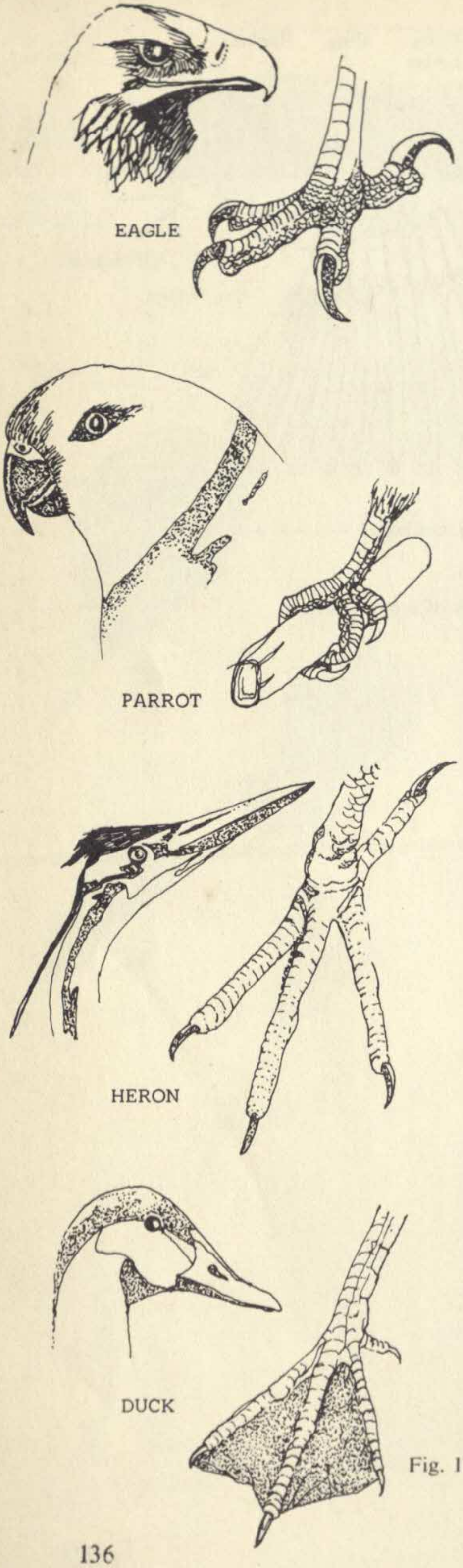
Fig. 13.4. Parts of a bird's wing

between certain of the bones. One of these folds is found across the armpit, while the other extends from the upper arm to the wrist.

Method of Flying. The bird flies mainly with the aid of the wings, while the tail-feathers help mainly in balancing; when the bird is landing it also spreads out its tail-feathers to serve as a brake. Steering is occasionally aided by the tail-feathers, but is often carried out by the tips of the wings.

The structure of the wing is related to its function in flying. Thus when the wing is extended, it is not straight, as we found above, and in addition, neither is it perfectly flat. It is somewhat curved, with its convex surface upwards and the concave side below. For a bird to fly forwards and upwards, the wings are moved up and down. When the wings are raised above the back and then pulled downwards, the feathers are held so that air is compressed below the wings and this supplies the force which carries the bird upwards and forwards. In the upward movement, the feathers are opened to allow air through. During the up-and-down movements of the wings the tip of each wing also moves in a figure-of-eight, and plays an essential role in the process of flight. As mentioned above, the tip of the wing also helps in steering. Thus when the bird is turning to the left, for example, it increases the beat of the hand and the primaries on the right wing, while it is the beat of the hand and primaries on the left wing which are increased when turning to the right.

Habits. Birds generally moult once a year—that is, lose the old or damaged feathers and grow new ones in each follicle to replace the lost ones. This is an orderly and gradual process and avoids having portions of the body bare at any time, or making flight difficult. To avoid the



latter, the large feathers on the wing and tail are moulted in symmetrical pairs. Complete moulting of the fowl takes several weeks.

Birds vary in their feeding habits, which are related to the shape of beak and feet (Fig. 13.5). The fowl, for example, is an omnivorous feeder and has a simple, strong, pointed beak which can deal with all kinds of food. It also has strong feet with blunt nails for scratching the surface of the earth in search of seeds and earthworms. As the bird has no teeth it swallows its food whole; this is stored in the crop to soften before it passes to the part of the stomach called the *gizzard* where it is ground up. Small stones may be eaten to help the gizzard in grinding the food.

The fowl has a poor sense of smell, but rather highly developed sight and hearing.

Birds on the whole have such interesting habits that 'bird-watching' is a popular hobby throughout the world. One of the fascinating aspects of their life is that of migration. Birds migrate over short or long distances for breeding purposes, to avoid the wintry weather of the temperate climates or to feed. They may return to the same spot where they nested in previous years. Birds such as the curlew and plover, for example, leave the West Indies for Canada and Alaska to breed. The tropical parrots and other birds of the forest migrate into gardens in towns to feed on palm fruits when they are in season. In West Africa the kite and the buff-backed heron live in the savanna country during the wet season, but travel to the forest when water is scarce in the dry season.

Most birds have the ability to produce calls or songs. Crows and similar birds can make special notes, which convey different ideas to others of their species; parrots, for example, have the power of *mimicry* —that is, imitating voices of people. The fowl produces notes to call its young, or warn them in the event of danger. Man has learnt to identify different species by means of their song.

Life-history. Birds show interesting methods of courtship before mating. In the fowl, the cockerel (or male) goes through his courting performance to attract the hen (the female) and to drive away his rivals; this includes dancing to display the beauty of his plumage, which is often much more brilliantly coloured than is that of the hen. When she is won over, the cockerel mounts the hen and mating takes place. Spermatozoa are discharged in this process to fertilize the soft eggs in the *oviducts* of the hen. After this, the fertilized egg travels down the oviduct, where a substance is secreted which hardens into the hard calcareous shell. The eggs are laid in a clutch at the rate of one a day.

The hen, as in birds generally, shows maternal care for its eggs by incubating them for about twenty-one days. During this period the embryo inside the egg receives warmth from the hen, and also respires freely, since gases (oxygen and carbon dioxide) are able to diffuse through the porous shell. The embryo gradually develops into the young chick which feeds on the yolk and albumen in the egg. At the end of the incubation period the chick uses its beak to peck a hole in the shell and succeeds in splitting it. It then emerges from the shell with its body covered with velvety down feathers.

Fig. 13.5. Adaptations of beak and foot of birds for different modes of life

SUGGESTED PRACTICAL WORK

1. *Reptiles.* In the tropics it is very easy to study reptiles at close quarters. The following animals can be observed very conveniently in the places listed below:

(*a*) *Geckos:* in any house or classroom after dusk.

(*b*) *Lizards and Skinks:* on any school compound.

(*c*) *Chameleons:* on school or house compounds, amongst vegetation on farms, and in the 'bush'.

(*d*) *Monitor lizards:* in swampy areas and near rivers and streams.

Other reptiles may also be encountered from time to time—for example, crocodiles, turtles (both fresh-water and marine species), and snakes.

Write a report on some of these reptiles along the following lines:

(*a*) *Gecko.* Total body length; position of sense-organs on head; modifications evident on digits of fore- and hind-limbs; colour of skin in relation to colour of immediate environment; feeding habits; type of eggs; duration of egg stage—from laying to hatching.

(*b*) *Lizard and Skink.* Length of tail and body; colour of dorsal and ventral body surfaces; length of limbs in relation to size of body; locomotion; behaviour to other lizards and other animals.

(*c*) *Chameleon.* Position and movement of eyes; size of mouth, length of tongue, and feeding habits (keep a chameleon in a cage without food for a whole day, then release it and observe it catching its food); use of tail; position of digits on both limbs during movement along a branch; colour changes in relation to light and shade and other environmental conditions.

Chameleons are *not* dangerous animals despite the belief in some places that they spit out poison. Chameleons are ugly, have a frightening appearance, and sometimes behave in an alarming way—for example, lateral flattening of the body, and hissing through the widely opened pink mouth. Nevertheless, these animals are quite harmless and make a fascinating study.

(*d*) *Monitor lizard.* Colour pattern of skin; mode of locomotion; relation between tail and body length; structure of the feet; feeding habits.

2. Some West African snakes are very poisonous indeed—for example, the gaboon vipers, green mambas, and the black cobras. There is no easy way of telling whether a snake is poisonous or harmless, but as a general rule it is true to say that snakes with large heads, thick bodies, and small tails are very poisonous. Live snakes should not be examined, but observations should be made on dead snakes.

Read the following paragraph and attempt to answer the questions by making the appropriate practical investigations.

The traditional way of killing a snake is to break its back with a blow from a large stick, and then to crush the snake's head with a club. Why is it that the snake cannot move along the ground even if its back is broken in one central place only? Some people cut off the head and the tail of a dead snake and bury them in the ground. Is there any scientific basis for treating the snake's tail in this way? What *exactly* are the fangs of a snake? Where is the venom, or poison, made in the body of a snake? What, precisely, is the function of the tongue of a snake? Is the snake's tongue ever dangerous to human beings?

3. *Birds.* Examine dead male and female house fowls and note: their relative sizes; feather colour; shape, size, and colour of comb, beak, and claws. How can you tell the difference between the sexes?

4. Pluck some of the different types of feathers on the fowl, and examine them in detail with the aid of a hand-lens. Draw and label the following parts of a quill feather: quill, rachis (shaft), and vane, barbs, and barbules.

5. It has been observed that in communities of hens, there is quickly established a phenomenon known as the 'pecking order'. That is, fowl A will peck fowl B, and fowl B becomes submissive to fowl A; meanwhile fowl B will peck fowl C, and fowl C, though submissive to fowl B, will peck fowl D.

Try to observe the behaviour of a group of hens in an open chicken-run (not in a battery), and see if you can recognize a definite rank or 'pecking order'. Does this order of 'superiority' change as the birds become older, or when they moult?

6. Observe birds in the countryside and take particular note of their feeding habits and general behaviour. Visit a zoo, if possible, and study the beaks and claws of as many different kinds of birds as you can—for example, owls, kites and vultures, parrots, sun-birds, bush-fowl, plantain-eaters, and kingfishers.

7. Make a diary of the dates of arrival and departure in your particular area of any migrant birds—for example, the cattle egret.

CHAPTER FOURTEEN

General Characteristics of Mammals

WE now come to study the mammals. These are regarded as the most highly developed class of animal because of the complexity and specialized development of their brains. Mammals include such well-known animals as the dog, the cat, the rabbit, the guinea-pig, the rat, the sheep, and the monkey. Man is also a mammal. From these few examples it appears that mammals generally walk or run on four legs (except man). But man is not the only exception in the matter and it is worth noting that the bat—which flies—and the whale—which swims in the sea like a fish—are in fact also mammals. At one time most of the animals which come under the class of mammals were referred to as 'beasts', 'quadrupeds', or simply as 'animals', but these terms should not be used in biological studies.

General Characteristics of Mammals

Mammals are like birds in being *warm-blooded* (or constant temperature) animals, that is, the temperature of the blood is regulated and remains constant within the body whatever the temperature of the air outside. In man, for example, the temperature of the blood remains at about 36·7 °C, whether he is living near the Equator or near the Arctic Circle, except when he is ill. Apart from this slight resemblance to birds, mammals have a number of special features, as mentioned below, which distinguish them as a separate class of animal.

Hair. All mammals are covered with hair, which is a form of exoskeleton like the feathers of birds or the scales of reptiles. The hairs may cover the whole body of the mammal, as in the rabbit, or they may only be in scanty patches on the body, as in the elephant.

Mammary Glands. The female mammal possesses *mammary glands* which secrete milk for feeding the young. The name 'mammal' is actually derived from the presence of the mammary glands.

Viviparous Form of Reproduction. With the exception of two Australian mammals which lay eggs, all mammals show this type of reproduction, that is, the young one is retained for some time within the body of the mother where it develops to an advanced stage. It is finally born alive, resembling its parents.

Teeth of Several Types. The teeth of mammals are not all of the same type (*homodont*) as in fishes and reptiles, but are of several types (*heterodont*).

External Ears. The ears of mammals have external fleshy parts, called the *pinnae*.

The Brain. In mammals the brain is large and complicated, and is the most highly organized brain found in animals.

Sweat-glands. Within the skin of mammals are sweat-glands which help in the removal of waste products from the body.

The Diaphragm. This is a muscular sheet which separates the chest cavity from the abdominal cavity, and is found only in mammals. All these features will be discussed in detail later.

External Features in Relation to the Environment and Habits

Mammals represent a highly successful adaptation of animals to life on dry land. Thus the environmental conditions under which they live are quite different from those of the fish and frog, although similar to those of birds. There is no need for scales, such as we find in fishes, since the atmosphere exerts little or no friction on the surface of the body, and the type of skin found in the frog is also unsuitable for dry land. As in birds, the high rate of metabolism of mammals results in a body temperature that is higher than that of the environment; thus the skin is adapted to regulate and maintain this high temperature, which enables mammals to remain active under wide variations in climate. Similarly the hair of mammals serves as a heat-insulator by containing air which checks the loss of heat from the body.

With such a system of conservation of heat, it may be necessary to bring down the body temperature if this gets too high. This is achieved with the aid of the sweat-glands in the skin which excrete sweat, the evaporation of which requires a certain amount of the body heat. Loss of heat from the body is also achieved when we exhale.

In parts like the palms of the hands and the under-surface of the feet, which are in contact with the ground, the skin is much thickened to form pads, as we find on our own palms or soles. The skin also forms the strong nails or claws which are at the tips of the digits in mammals. Added to these, mammals have highly developed senses of sight, hearing, and smell which aid self-preservation. Above all, the large brain has resulted in a large skull.

It is when we come to consider the various situations in which we find particular mammals, and also study their habits, with special reference to their modes of feeding, that we see the full range of adaptation in the external features found in mammals. Some of these will be discussed below.

Body Structure. Mammals differ in size and shape of the body. Those which are swift-running, such as dogs and deer, are often rather slender and have long limbs. The whale, seal, and other mammals which live in water have streamlined bodies like those of the fishes and birds. In burrowing mammals like the mole the body is often elongated.

The Neck. Grazing animals such as the deer and the horse have long necks. In the giraffe, which browses on trees, the neck is extremely elongated.

The Tail. The tail performs various functions in different mammals, and is suitably shaped in each case. In rodents such as squirrels which run and jump about, the tail is shaped to provide stability and balance; in some monkeys the tail can be used for grasping, and is therefore termed prehensile; in the whales the tail is flat, being used to propel the animal and also serve as a rudder; in the kangaroo the tail is stout and provides support and balance.

Limbs. The limbs of mammals are also varied. In swift-running mammals, such as deer and antelopes, the limbs are slim and taper gradually

to the foot, whilst in heavy mammals such as the elephants the limbs are far more massive. In burrowing animals, such as the mole, the limbs are short and the palms are broad. Finally, in the whales the front limbs are paddle-shaped and the back ones absent, whilst in the bats the fore-limbs and fingers are elongated to support the wing.

The Foot. The basic number of toes on each foot in a mammal is five. However, the number is reduced in running mammals such as the deer, sheep, and horse. For example, in the deer and sheep the third and fourth toes are enlarged but the second and the fifth ones are reduced to small structures. In the horse there is only one toe left on each foot.

Eyes. Mammals which feed on plants, such as rodents (for example, the rabbit and the squirrel) and hoofed mammals, like cattle and pigs, need to keep watch against their enemies when feeding in the open; thus the position of their eyes, which are at the sides of the head, is advantageous. On the other hand, the eyes of carnivores, such as cats and dogs, and primates, such as monkeys and man, are placed forward to provide binocular vision.

External Ear. In grazing mammals, like the deer and the horse, the external ear is large and readily movable, while it is rather small in burrowing animals. It is virtually absent in swimming mammals like seals.

The Skin of Mammals

We have already emphasized the suitability of hair as a body covering in the mammal. We will now describe the structure and function of the various parts of the mammalian skin.

Structure and Functions. A vertical section of the skin of a mammal (Fig. 14.1) shows that it is made up of two main layers; the outer layer. known as the *epidermis*, and the inner layer, the *dermis*. The epidermis, which is a protective layer, consists of an outermost layer of dead, hard, and rather flattened cells. They are usually rubbed off under friction and may be quite thick on parts of the body that are in contact with the ground. This forms the *cornified*, or *horny layer* which does not bleed or cause pain when cut. Beneath this layer is a living *granular layer*; at its base is the *Malpighian layer*, from which actively dividing cells are produced to replace the dead cells of the cornified layer as they are worn off.

Traversing the epidermis are the *hairs* and *sweat-glands* which arise deep down in the skin, but which really form part of the epidermis. Each hair arises from a narrow tube, the *hair-follicle*, which starts from the dermis. At the base of the hair is the *hair-papilla*, which produces the hair. This is supplied with blood-vessels and small muscles. The latter can contract to make the hair stand on end from its normal slanting position. A little higher up the tube, the oil-gland (or *sebaceous gland*) opens into the hair-follicle and produces oil to make the hair waterproof. Pigment is responsible for hair colour. The hair prevents loss of body heat by trapping a layer of still air.

The sweat-gland arises as a coiled structure well in the inner layer of the skin, and opens on the surface by the *sweat-pore*. The sweat-glands absorb water containing urea and some dissolved salts from the network

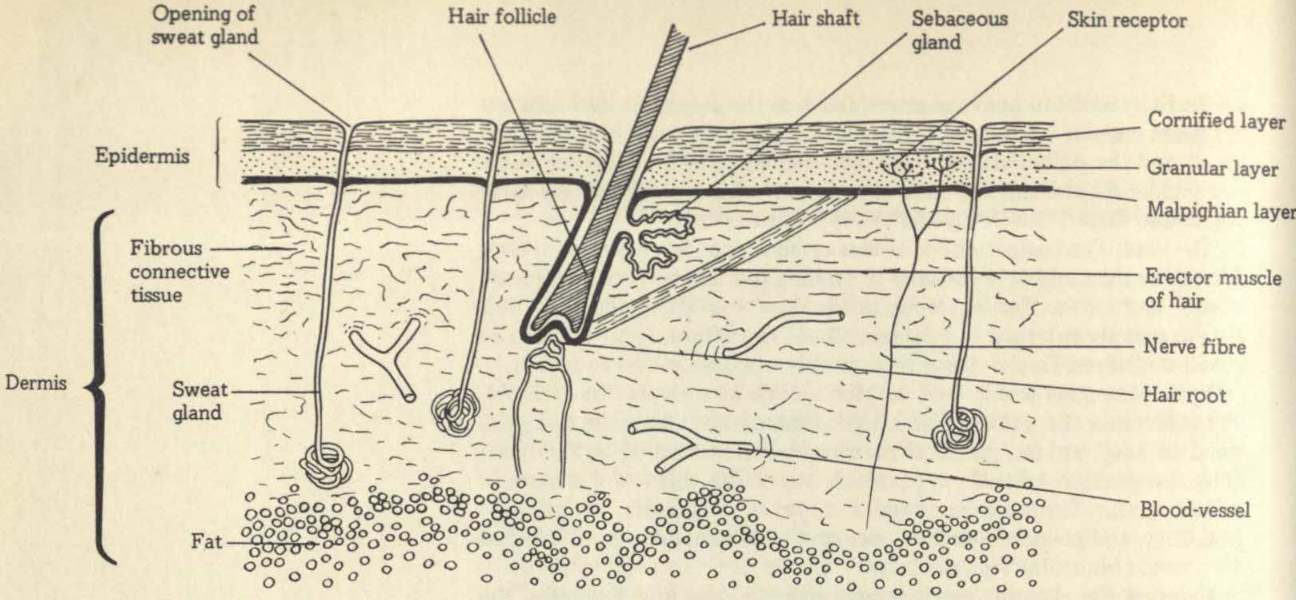


Fig. 14.1. Vertical section of mammalian skin

of small blood-vessels which surround them in the dermis. On reaching the sweat-pore the sweat evaporates from the surface of the skin, taking its latent heat of vaporization from the skin, and this helps in the regulation of the body temperature by cooling the skin. At the same time it aids in removing some excretory material from the body.

The second major layer of the skin, the dermis, consists of a collection of muscles, capillaries, and nerves and below all these are deposits of fat. The endings of nerves, which include the sense-organs of touch, are found much higher up in the dermis and epidermis. They receive stimuli, while the nerves are responsible for carrying the stimuli to the brain and spinal cord. The fat deposits below the dermis constitute a bad conductor of heat, which helps to conserve heat in the body. The capillaries transport food, oxygen, and waste products. The dermis is very thick in mammals such as whales which live in water.

To sum up, the functions of the mammalian skin are:

(*a*) To regulate the body temperature. This is carried out with the aid of the hair, the sweat-glands, and the fat deposits.
(*b*) To serve as a protective covering.
(*c*) To help in excretion by means of the sweat-glands.
(*d*) To receive stimuli (heat, cold, pain, and touch) by means of the nerve-endings and to transmit them to the central nervous system, by means of nerves.

Regulation of Body Temperature

Something has already been said on this, but here we must examine the subject in more detail. As mentioned above it is a great advantage that mammals and birds can maintain a constant body temperature, as this enables them to live in a wide range of climates, whether cold or warm.

Now the maintenance of a constant body temperature should involve mechanisms to raise the temperature when it begins to fall below a certain point and to lower it when it shows a tendency to rise overmuch. Heat energy, which raises the body temperature, is obtained

from the oxidation (during respiration) of food substances which we eat. The high rate of metabolism in mammals calls for a large quantity of food. The resulting output of heat energy, which is carried in the blood to all parts of the body, may accumulate and cause the body temperature to rise; thus the need for getting rid of excess heat.

There are at least three principal ways by which excess heat leaves the body. One of these is *breathing*. The temperature of the air we breathe out is higher than that of the outside air because the body is nearly always at 36·7° C. Thus whenever we breathe out, heat is being lost from the body through evaporation of water from the lungs. Since the air we breathe in is at a lower temperature, it means that it has to be warmed up to the temperature of the body when it gets into the body. This also means a loss of some of the body heat. About one-fifth of the heat lost from the body is accounted for by the processes related to breathing.

The second and third methods of losing body heat both make use of the *skin*. One is the production and evaporation of sweat, and the other consists of *conduction*, *convection*, and *radiation*, which are the ordinary physical processes of heat transfer. We have already dealt with some aspects of sweating when discussing the structure of the skin. The physical processes of heat transfer are rather important in man. The loss of heat in this way is greater when the outside temperature is high. When this happens the flow of blood through the capillary blood-vessels of the skin is increased. In such cases, the blood-capillaries increase in diameter to carry more blood.

So far we have mainly considered the ways by which body heat is lost. We now come to ways of conserving heat when necessary. One such method is the converse of the physical processes of heat transfer mentioned above. It is found that when the temperature of the outside air falls, the blood-vessels in the skin contract and prevent excessive loss of heat. The second method is the possession of hair on the skin which, as has been mentioned, serves as a bad conductor of heat by trapping a layer of air. In man the covering of hair is not enough, and he often adds clothes to it. Lastly, there is the possession of fat under the skin which is a bad conductor of heat and is particularly thick in whales and seals.

SUGGESTED PRACTICAL WORK

1. Visit a zoo to see different types of mammals. Study in detail the external features and adaptation of either the rabbit, the rat, or the guinea-pig to suit its way of life; note particularly the shape of the body, neck, tail, limbs, eyes, and ears.

2. Obtain some cells of the epidermis of your skin by gently scraping the inside of the mouth with your finger. Observe these in a drop of water under the microscope. Draw the cells.

3. Examine and make a drawing from a prepared slide of the skin of man or another mammal.

4. By using a $\times 10$ hand-lens it is possible to see the external openings (pores) of the sweat-glands in the following areas of the skin: along the forehead; at the end of the nose; along the margin of the upper lip; and on the palms of the hand.

CHAPTER FIFTEEN

The Skeleton and Teeth of Mammals

In the last chapter, we touched on the elements of the external skeleton, or exoskeleton, of mammals—such as hair, nails, scales, and hoofs. We are now to consider the internal skeleton, or endoskeleton, which provides the framework necessary to maintain the shape and support the body of the animal. The internal skeleton is so vital in this role that it is simply referred to as the skeleton.

The functions of the skeleton as a whole are:

(*a*) to give support to the body;
(*b*) to provide points of attachment for the muscles;
(*c*) to facilitate movement of certain parts of the body by means of a hinged system of levers;
(*d*) to protect certain delicate parts of the body. For example, the skull and the vertebral column protect the brain and the spinal column respectively.

The skeleton of mammals (Fig. 15.1), as of other vertebrates, consists of:

Skull Vertebral column (or backbone)	forming the *axial skeleton*
Limbs Limb girdles	forming the *appendicular skeleton*

These parts will now be considered in some detail.

The Skull

As mentioned above, the skull protects the brain, but it also gives shape to the head. The skull (Fig. 15.2) consists of three parts:

(*a*) the *cranium*, which is the box which holds the brain. This is made up of flat bones which interlock and fit together as in a jigsaw-puzzle. The cranium is relatively enormous in man, because of the highly developed brain.

(*b*) the *facial skeleton*, which supports the nose and the eyes, as well as the muscles of the cheek; and

(*c*) the *jaws*, which consist of the upper and lower jaws, and bear the teeth used in eating. The upper jaw is fused to the bones of the face; but the lower jaw is hinged to the rest of the skull and this enables the mouth to be opened and closed. Behind the hinge of the lower jaw is a flask-shaped set of bones which contains the inner ear.

There is a large hole, the *foramen magnum*, right at the back of the skull, and it is through this hole that the brain is joined to the spinal cord. The skull articulates with the first vertebra of the vertebral column

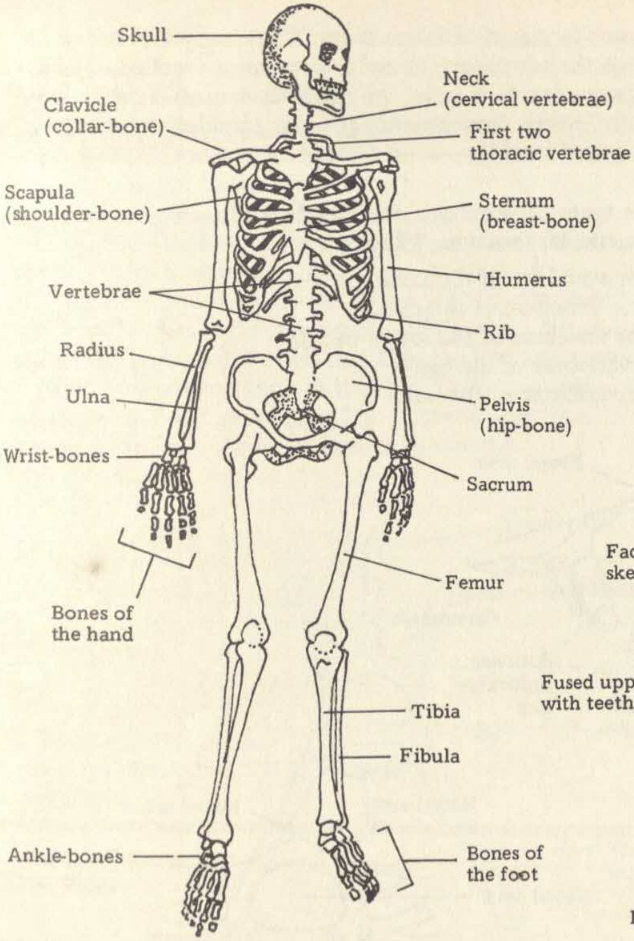


Fig. 15.1. General plan of human skeleton

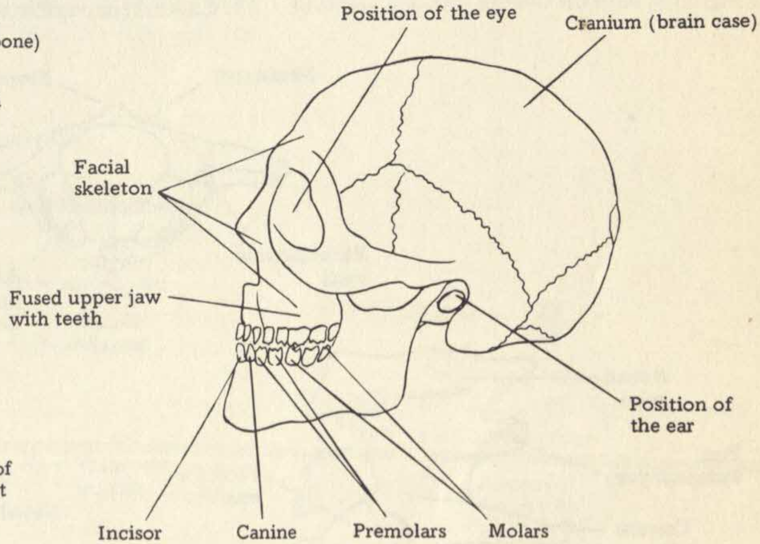


Fig. 15.2. Parts of human skull

by means of flat surfaces called *occipital condyles*, situated on either side of the foramen magnum.

The Vertebral Column

The vertebral column, or backbone, consists of a series of small bony rings, called the *vertebrae*, forming a hollow tube which protects the spinal cord. The vertebrae are united to one another by fibrous tissue which restricts their movement on each other; they are separated from each other by pads of cartilage.

A vertebra (Fig. 15.3) is composed of a body, the *centrum*, carrying an arch of bone, the *neural arch*, at the top of which is the *neural spine*, which projects backwards and upwards and to which the muscles of the back are attached. At each side of the neural arch is a projection called the *transverse process*, to which muscles are attached in the body of the animal. The neural arch also carries two small over-lapping projections, one in front and the other behind, which articulate with those

of their neighbours by means of flat surfaces. This arrangement restricts the movement of the vertebrae. These projections are called *zygapophyses.* At the base of each of these, the neural arch is notched in front and behind, and through these notches pass the spinal nerves on their way out of the spinal cord.

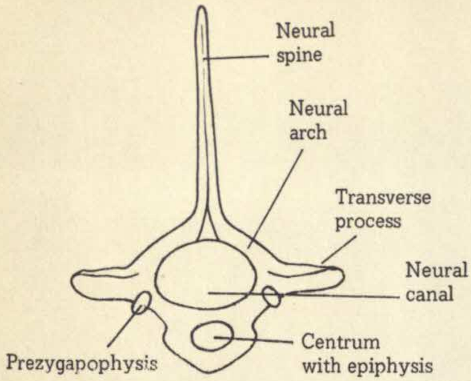


Fig. 15.3. A model vertebra (thoracic vertebra)

There are five types of vertebrae, the members of each group being adapted for a particular function. These are:

1. Cervical (or vertebrae of the neck).
2. Thoracic (or vertebrae of the chest).
3. Lumbar (or vertebrae of the lower back).
4. Sacral (or vertebrae of the hip).
5. Caudal (or vertebrae of the tail).

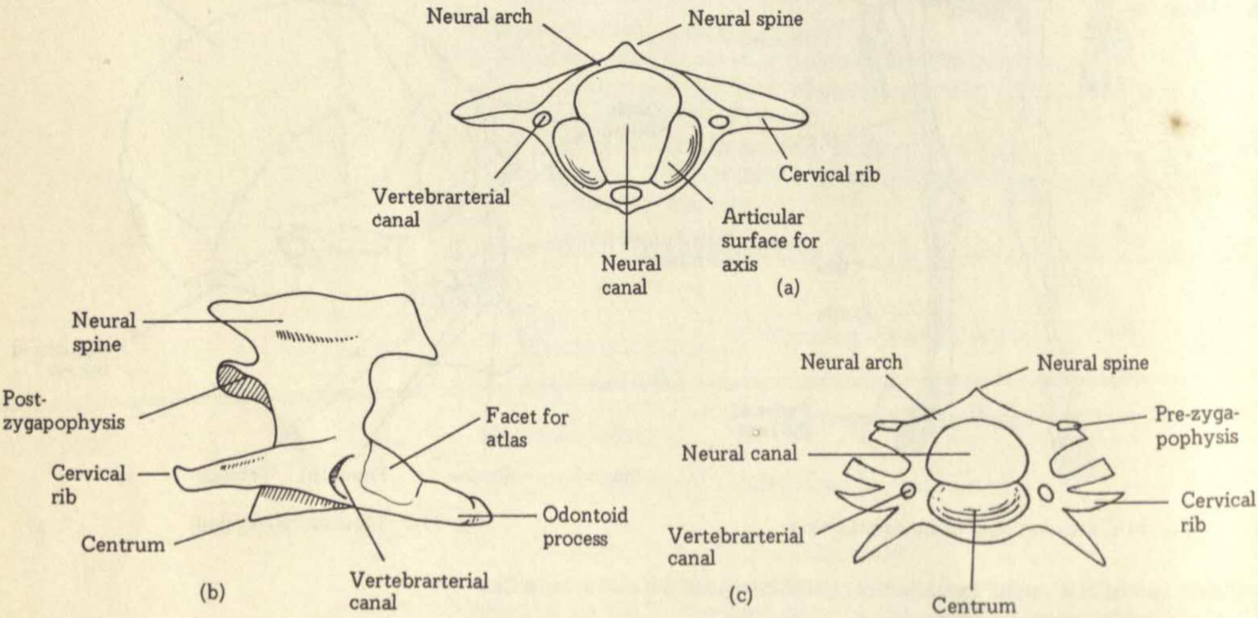


Fig. 15.4. Cervical vertebrae: (*a*) atlas; (*b*) axis; (*c*) typical cervical vertebra of rabbit

The structure and functions of these types of vertebrae will now be discussed.

Cervical Vertebrae. Typically, a cervical vertebra has a short neural spine and a hole in each transverse process. The transverse process divides into two short parts at its end. The first two cervical vertebrae are shaped differently from the others and are adapted for the function of supporting the head and allowing movement of the skull on the vertebral column. The first of these is called the *atlas* (Fig. 15.4) and has no centrum, a broad, flattened transverse process, and a large neural cavity divided into two by a transverse ligament. On the front of the atlas are two large cavities which receive a pair of knobs at the base of the skull. The head can nod on the atlas.

The second vertebra is called the *axis* (Fig. 15.4). It can be distinguished by the fact that its centrum is produced into a peg-like process (the *odontoid process*) which projects into the lower cavity of the neural canal of the atlas. This arrangement allows the atlas to twist about the axis, and thus enables the head to be turned easily. The neural spine on the axis is large. Apart from the atlas and the axis there are five ordinary cervical vertebrae (Fig. 15.4).

Thoracic Vertebrae. (Fig. 15.3.) The above description of the typical structure of a vertebra applies closely to the thoracic vertebrae. The latter have rather long neural spines for the attachment of the muscles of the shoulders and the ligaments of the skull. The thoracic vertebrae are in the region of the ribs, and thus the transverse processes have flat facets which connect them to the ribs. There are twelve or thirteen pairs of these in most mammals. The thoracic vertebrae, the ribs, and the breast-bone form the bony cage of the thorax.

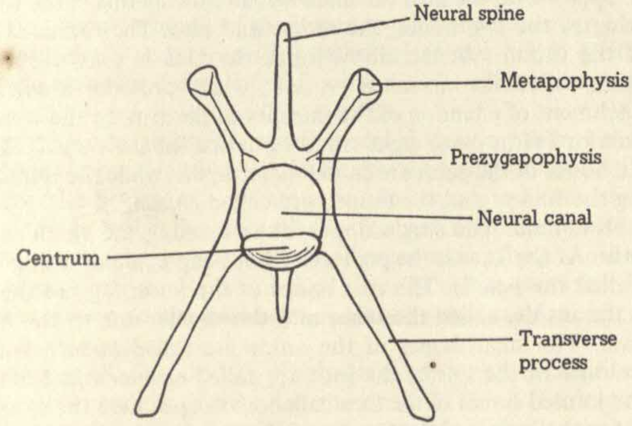


Fig. 15.5. Lumbar vertebra

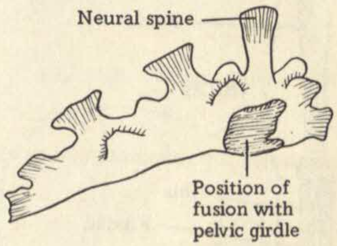


Fig. 15.6. Fusion of sacral vertebrae to form sacrum

Lumbar Vertebrae. (Fig. 15.5.) These vertebrae have to carry the weight of the upper or front part of the whole body of the mammal. They are thus particularly large and strongly built. The transverse process is well developed and divided into upper and lower parts to provide an increased surface for the attachment of muscles. The first and second lumbar vertebrae each bear a short projection below the centrum. There are five to seven lumbar vertebrae in the mammal.

Sacral Vertebrae. The vertebrae here are fused together to form a strong base which, with the pelvic girdle, forms the pelvis. The pelvis protects the main organs of the abdomen. Some vertebrae are usually fused together to form the sacrum (Fig. 15.6).

Caudal Vertebrae. These vertebrae form the tail where it is present, so the number varies, and in man and other tailless mammals only small remnants or vestiges are found. In man these are four bones forming what is called the *coccyx*.

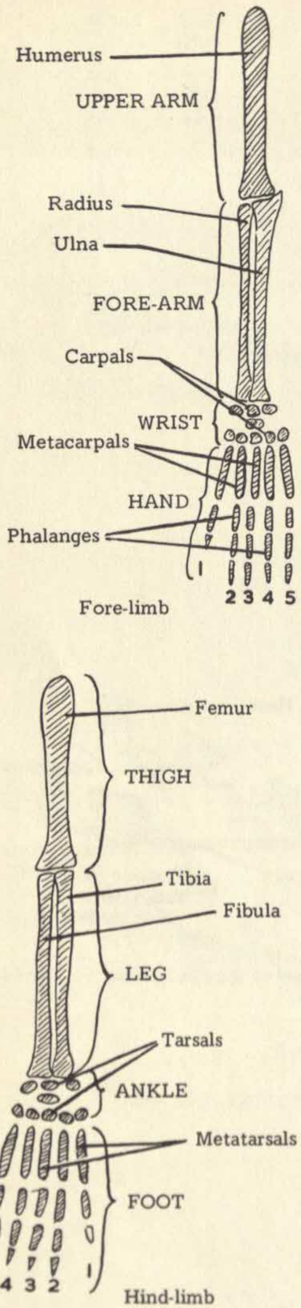


Fig. 15.7. Pentadactyl plan of vertebrate limbs

The Limbs

As mentioned in the study of the toad, the vertebrates, with the exception of the fish, have developed limbs built on the pentadactyl, or five-fingered, plan. The main part of the limb is made up of a proximal bone (which is attached to the limb girdle) next to the body, and two other bones. Then comes a series of small bones which form the wrist or ankle, followed by five rod-like bones of the palm of the hand or the sole of the foot. At the end of these are the small bones, forming the joints of the fingers or toes. Thus the fore- and hind-limbs have essentially the same pattern, but the corresponding bones are given different names. Fig. 15.7 illustrates the plan outlined above, and gives the common and scientific names of the constituent bones. A general description will be made of the limb bones with emphasis on modifications of those of the mammal.

The Fore-limb. The single bone nearest the body, which forms the arm or upper arm, is called the *humerus*. Following this is the fore-arm consisting of the two bones, the *radius* and *ulna*. The radius is on the side of the thumb. At the elbow joint, the ulna is drawn out into a projection called the *olecranon process*, which provides a surface for the attachment of a tendon of the muscles of the arm. In the wrist there are seven or (as in man) eight small bones called the *carpals*. The five rod-like bones of the palm are called *metacarpals*, while the jointed ones forming the fingers and the thumb are called *phalanges*.

The Hind-limb. The single upper bone forming the thigh is called the *femur*. At the knee is the protective knee-cap made of a single small bone called the *patella*. The two bones of the lower leg are the larger one to the inside, called the *tibia*, and the smaller one to the outside, the *fibula*. The small bones of the ankle are called *tarsals*, while the rod-like ones of the sole of the foot are called *metatarsals*. Finally, we have the jointed bones of the toes called *phalanges*; here the same name is used for the bones of the fingers of the fore-limb.

The various bones of the limbs of vertebrates are found to be specially modified to suit the habits of the particular animal. We have already come across the modifications in the toad (Chapter 11) and the bird (Chapter 12). In mammals we find that the limb bones of man, the bear, and some climbing forms have a relatively slightly modified structure, as described above, which is very adaptable, but the hoofed mammals such as horses, which run, have longer limbs and a reduced number of toes. In the case of hoofed mammals the bone structure is so modified that one could say that their heels are raised and they walk on their toes. In the bat, the bones of the hand are enormously elongated, and the long fingers support the membrane of the wing.

The Limb Girdles

The limb girdles are bones within the body which act as supporting framework to which the limbs are jointed. The limb girdle for the fore-limb is called the shoulder, or *pectoral girdle*, and that of the hind limb, the hip, or *pelvic girdle*. They also follow a basic plan in all vertebrates,

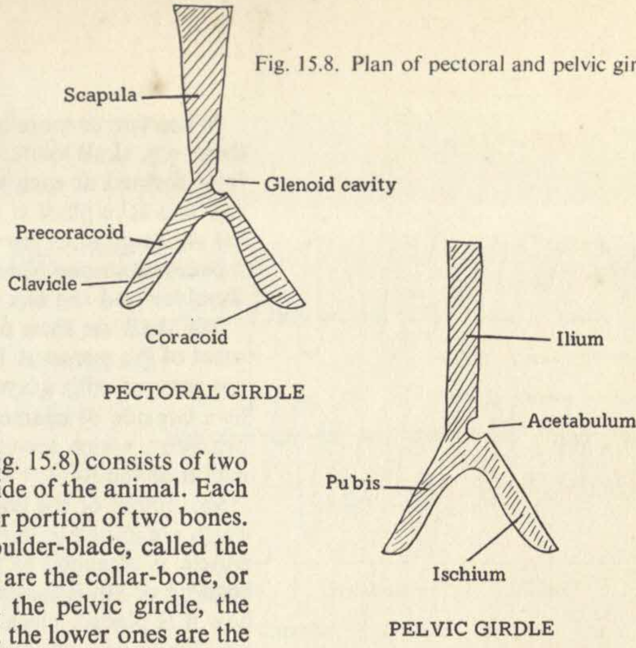


Fig. 15.8. Plan of pectoral and pelvic girdles

as in the case of limbs. Typically, each girdle (Fig. 15.8) consists of two symmetrical parts jointed midway at the lower side of the animal. Each half has an upper portion of one bone and a lower portion of two bones. In the pectoral girdle the upper bone is the shoulder-blade, called the *scapula*, and the two bones of the lower portion are the collar-bone, or *clavicle* (anterior), and *coracoid* (posterior). In the pelvic girdle, the upper bone is the hip-bone, called the *ilium*, and the lower ones are the *pubis* (anterior) and the *ischium* (posterior).

In mammals, the girdles are more modified than in other vertebrates such as toads, reptiles, and birds. In the pectoral girdle (Fig. 15.9) there is a cavity (the glenoid cavity) between the scapula and the clavicles. It is into this hole that the humerus fits, forming a ball-and-socket joint. The coracoid is much reduced to a small process near the glenoid cavity. The pectoral girdle is attached below directly to the sternum, but its connection above to the backbone is only by means of muscles. It is thus capable of movement.

The pelvic girdle (Fig. 15.10) also has a cavity at the junction between the upper ilium and the lower pubis and ischium. This is the *acetabulum*, into which the femur fits. The ilium on each side is firmly attached to the sacrum to form the pelvis, while the pubes on the two sides meet together below. The pelvic girdle is thus not movable.

Fig. 15.9. Pectoral girdle (scapula)

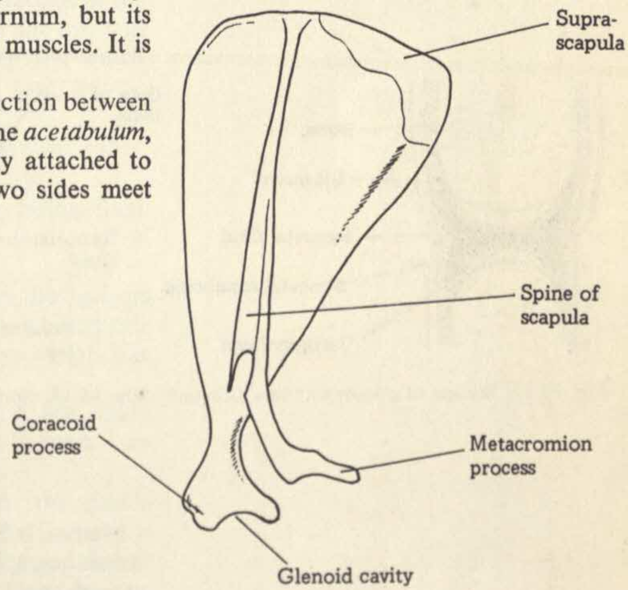
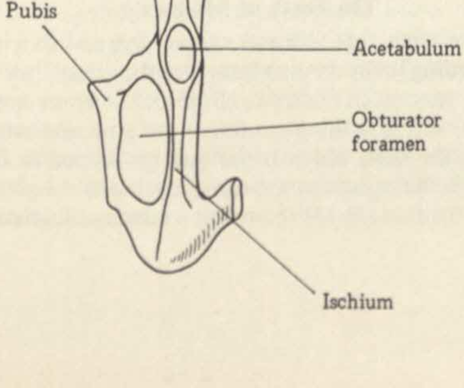


Fig. 15.10. Pelvic girdle



Joints and Articulations

When two or more bones meet each other a *joint* is formed. Some are fixed, *e.g.* skull joints; others move with the aid of muscles. The type of joint formed at each junction determines the nature of the movement that can take place at that joint. The two well-known types of joint are (*a*) *the hinge type*, found in the elbow and the knee, which allows free movement in one plane only and (*b*) the *ball-and-socket type*, found in the shoulder and the hip, which allows movement in almost all directions.

We shall use these to illustrate the nature and role of joints in movement of the mammal. In order to prevent friction, the ends of each bone are covered with a layer of cartilage, and the bones are bound together by a capsule of ligaments. There is often a membrane inside the set of ligaments which secretes an oily fluid (the *synovial* fluid) to aid lubrication of the joint (Fig. 15.11).

Movement of the bones at the joint is brought about by the muscles which are joined to the bones by strong fibrous tissue, the *tendons*. Each muscle is attached to at least two bones, so that it can bring about bending or straightening of the bones when it contracts, depending on how it is placed. Usually the muscles are arranged in pairs and in this way while one of them can cause a bend in the joint, the other can straighten it. The movement of a limb, for example, depends on many such pairs of muscles which act in co-ordination.

The hinge type of joint is illustrated by the elbow and the knee; the ball and socket type is shown by the shoulder and the hip (Fig. 15.12).

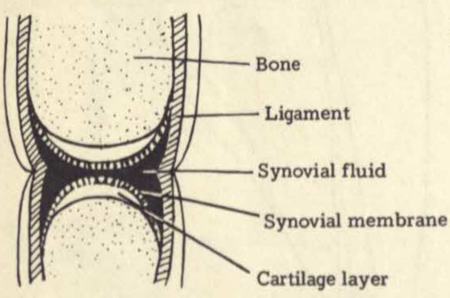


Fig. 15.11. Section of a joint to show structure

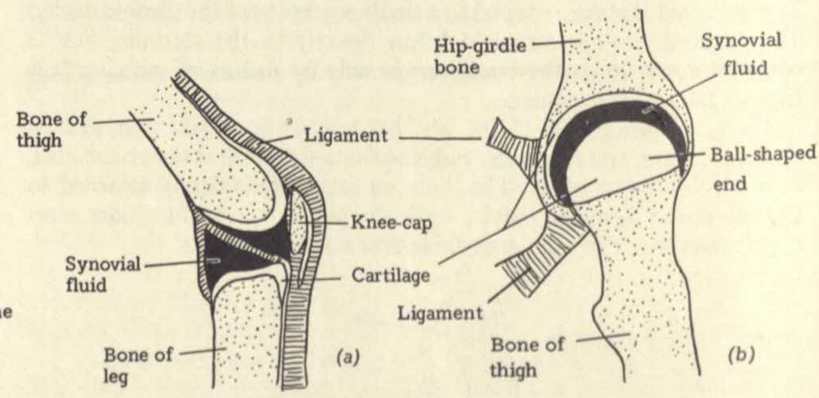


Fig. 15.12. Some joints in mammals: (*a*) the knee as a hinge; (*b*) the hip as a ball and socket

The Teeth of Mammals

Mammals have teeth that differ in shape, size, and to a limited extent in number, according to the feeding habits of the group, but the structure of each tooth is very much the same (Fig. 15.13). There are three parts of it: the *crown*, which is the part above the gum and which projects into the mouth; the *root*, which is the part embedded in the jaw; and the *neck*, which is the region on the same level with the gum and where the crown joins the root. Inside the tooth a substance called *dentine* fills

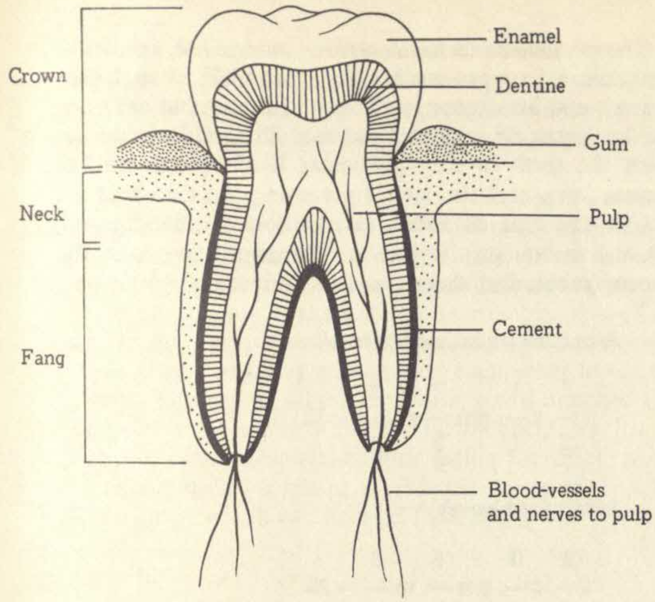


Fig. 15.13. Structure of a mammalian tooth

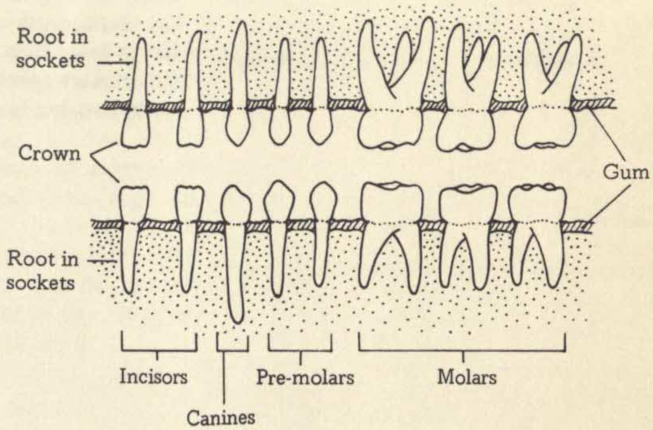


Fig. 15.14. Structure of teeth of man

the greater part. Dentine is hard but resilient and therefore is able to resist strong pressures but is incapable of withstanding wear. Consequently a protective layer of a hard substance called *enamel* covers the dentine in the region of the crown and the neck. In the region of the root the dentine is covered with *cement*, which helps to fix the tooth in its socket. The dentine itself surrounds a central *pulp cavity*, which contains soft, living tissue supplied with blood-vessels and nerves. These pass through a tiny hole at the base of the root.

There are four types of teeth in man (Fig. 15.14) and most other mammals. From the front of the mouth to the back these are:

(*a*) *Incisors.* These are flattened, chisel-like teeth for biting food. There are four in each jaw of man. Incisors are well developed in gnawing mammals like mice, rats, and squirrels.

(*b*) *Canines.* These are more pointed and stronger than the incisors and are used for tearing. In man there are two in each jaw on either side of the incisors. They are most developed in flesh-eating mammals like dogs, cats, and leopards and are absent in the rabbit.

(*c*) *Premolars.* These are small teeth with broad crowns, a few sharp points for cutting, and flat tops for chewing and grinding. In man there are four of them, placed in pairs after each canine tooth.

(*d*) *Molars.* Together with the premolars, these form the cheek-teeth. They are often not easy to distinguish, but it is known that the molars are not found in the temporary set of milk-teeth formed during childhood, but only in the permanent teeth. The temporary set in man consists of four incisors, two canines, and four premolars in each jaw. Their growth is completed at about the age of two and they serve the child until he is about six, when the permanent teeth begin to replace the temporary ones. The molars appear after the other permanent teeth

have grown out. The permanent teeth, as already mentioned, consist of four incisors, two canines, four pre-molars, and six molars in each jaw.

The number, kind, and arrangement of teeth in a mammal are often indicated briefly by means of a *dental formula*. In this formula the numbers represent the teeth of any particular kind in one half of the upper and lower jaws, and the letters preceding the numbers are the initial letters of the type of teeth, *i.e.*, incisors (i), canines (c), pre-molars (pm), and molars (m). Below are the dental formulae for man, two herbivores (rabbit and sheep), and a carnivore (dog).

Man (permanent teeth) (omnivore)

$$\mathrm{i}\,\frac{2}{2},\ \mathrm{c}\,\frac{1}{1},\ \mathrm{pm}\,\frac{2}{2},\ \mathrm{m}\,\frac{3}{3} = 32$$

Rabbit (herbivore)

$$\mathrm{i}\,\frac{2}{1},\ \mathrm{c}\,\frac{0}{0},\ \mathrm{pm}\,\frac{3}{2},\ \mathrm{m}\,\frac{3}{3} = 28$$

Sheep (herbivore)

$$\mathrm{i}\,\frac{0}{3},\ \mathrm{c}\,\frac{0}{1},\ \mathrm{pm}\,\frac{3}{3},\ \mathrm{m}\,\frac{3}{3} = 32$$

Dog (carnivore)

$$\mathrm{i}\,\frac{3}{3},\ \mathrm{c}\,\frac{1}{1},\ \mathrm{pm}\,\frac{4}{4},\ \mathrm{m}\,\frac{2}{3} = 42$$

Diet and Dentition

As we have indicated above and elsewhere, the modifications of the teeth found in different mammals are related to their diet and mode of feeding.

Omnivores. Mammals which feed on a mixed type of food are called *omnivores* and have teeth which are relatively simple and look more or less alike. Man and the pig are in this group of mammals. As we found in the case of man (Fig. 15.14), the two pairs of incisors in the upper jaw are broad with sharp cutting edges, while the single pair of canines are bluntly pointed. The premolars have two blunt cusps, and each molar in the upper jaw has three or four cusps.

Herbivores. Those mammals which feed on vegetation are said to be *herbivorous*. Horses, cows, and sheep are examples. We have given the dental formula for the rabbit and the sheep above. Mammals such as these have extremely long incisors which continue to grow throughout life and which have a sharp edge like a chisel (Fig. 15.15), very suitable for cutting grass or other vegetation. Often the canines are absent since

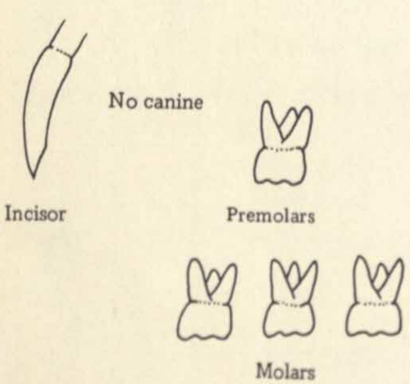


Fig. 15.15. Structure of teeth of rat (herbivore)

they are not needed, although the sheep has one pair of canines in the lower jaw. The space left by the absence of the canines is often used to hold food as it is gnawed. The premolars and molars are ridged transversely, making them suitable for grinding up food by sideways movements of the jaws.

Carnivores. (Fig. 15.16.) These are flesh-eating mammals and all their teeth are sharp and pointed for the purpose of cutting and tearing flesh. In the dog the incisors are small and pointed, but the canines are especially large, curved, and pointed. The premolars also have one or more sharp points; the last upper premolar as well as the first lower molar are exceptionally large and are given the name of *carnassial teeth*. These work by sliding past each other to cut off flesh from the bones. The way in which the lower jaw is attached to the skull allows only upwards and downwards movements, and this makes it possible for the lower carnassial to bite within the upper one. The molars are primarily used for crushing, although some of them have one, two, or three cusps which can be used for cutting flesh when necessary.

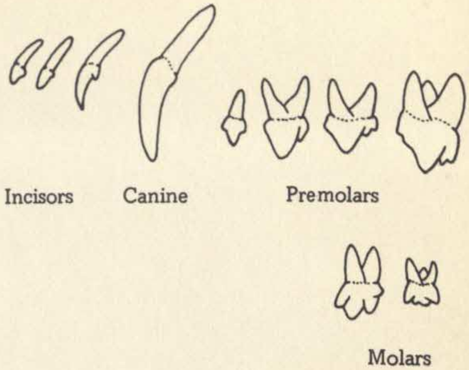


Fig. 15.16. Structure of teeth of dog (carnivore)

SUGGESTED PRACTICAL WORK

1. *Bones.* (*a*) Your teacher will supply you with the bones of a mammal. (To prepare these he first dissected the animal and boiled the carcass in water until the attached muscles were easily removed.) Make careful drawings of a cervical, thoracic, and lumbar vertebra. Also study the humerus, the radius and ulna, the femur, the scapula, and the bones of the pelvic girdle.

(*b*) Bones consist largely of calcium compounds. Place a piece of bone in dilute hydrochloric acid for a few days; note that it dissolves, leaving only a shred of organic matrix.

(*c*) By considering the bones of your own skeleton, try to calculate the total number of bones in the human body. (The skull is made up of twenty-two bones.) What is the name of the longest bone in the human body?

2. *Joints.* Obtain some fresh bones of a mammal, such as a sheep, goat, or rabbit, from a butcher and study the construction of either the elbow and the shoulder or the knee and the hip.

What bones and joints are involved in the movements of *pronation* and *supination*? (*Note:* The position of pronation is achieved by placing the arms in front of the body, with the palms of the hands facing downwards; supination results from turning the hands so that the palms face upwards.) Can any other animals, apart from man, exhibit pronation and supination?

3. *Teeth.* Remember that each of you in the laboratory is a mammal. Examine the teeth of a friend. Make a note of the number of each type of tooth, and write out your friend's dental formula, noting any lost teeth.

4. Inspect the teeth of children of various ages—for example, babies aged six months, ten months, fifteen months, and two years, and children aged six years, ten years, and fifteen years. Record the names of the milk-teeth in the order in which they appear. Also list the ages at which the permanent teeth appear in children.

5. Examine the mouth of a dog, a goat, a sheep, a horse or cow, and a pig, and count the different kinds of teeth present on both upper and lower jaws. Does it seem to you that the teeth of each animal are suited to the kind of food it eats, or not?

CHAPTER SIXTEEN

Food, Diet and Health

BEFORE we consider digestion in mammals, we should first learn about their food. All living organisms require food for the following purposes:

(1) To provide energy, produced by oxidation of the food.
(2) To supply the material needed for growth.
(3) To repair and replace deteriorating cells of the body.
(4) To afford protection against disease and ill-health.

The food-stuffs taken in by animals are generally ready-made combinations of six main classes of substances. These are *a*) (carbohydrates, (*b*) proteins, (*c*) fats and oils, (*d*) mineral salts, (*e*) water, and (*f*) vitamins. It is worth examining certain facts about each of these classes of foods.

Carbohydrates

Carbohydrates are oxidized in the body to provide energy for muscular work. A carbohydrate is defined as a compound of carbon, hydrogen, and oxygen, in which hydrogen and oxygen are present in the same proportions as in water (that is, with twice as many atoms of hydrogen as there are of oxygen). The main types of carbohydrates used as food by mammals are sugars and starches, and they are both formed by green plants. The sugars are the first substances to be formed during photosynthesis in the leaf and they can later be concentrated into starch. There are two types of sugars, known as simple and complex sugars. Forms of simple sugars are *glucose* (or grape-sugar) and *fructose* (or fruit-sugar). Complex sugars comprise *sucrose* (or cane-sugar), *maltose* (or malt-sugar), and *lactose* (or milk-sugar). Starch exists in only one form. The simple sugars occur in Nature in dried raisins, sweet fruits, honey, and the roots and leaves of some plants. They have a sweet taste and dissolve slowly in water.

The complex sugars are found in large quantities in sugar-cane (sucrose), in the breast-milk of mammals (lactose), and in malt-extract (maltose). They are far more soluble in water and are easily converted (by hydrolysis) into simple sugars by enzymes or by acids.

The starches are found in various food substances well known in many tropical diets such as rice, potatoes, cassava or manioc, and yams. They are cheap foods, compared with proteins and fats, and they are easily digested. Natural sugars as found in fruits and honey are easily assimilated by the body tissues.

Tests for Sugars and Starches. It is possible to identify the type of carbohydrate that is present in any food substance. In the case of the sugars, the common test is based on their ability to reduce salts of

copper, present in Fehling's solution, to insoluble cuprous oxide. This reaction, which only works in an alkaline solution, is shown by the change of the clear blue Fehling's solution (provided in the laboratory) into an opaque, insoluble, brick-red cuprous oxide precipitate. All the simple sugars, as well as nearly all the complex sugars which reduce copper oxide as shown above, are referred to as *reducing sugars*. A complex sugar like sucrose which does not give such a reaction is called a *non-reducing sugar*.

Fehling's test for reducing sugars. Fehling's solution is usually provided in two separate bottles which are labelled 'Solution A' and 'Solution B' (or 'Solution No. 1' and 'Solution No. 2'). Add together equal quantities of the two Fehling's solutions, and pour some of the mixture into a test-tube. Next add an equal volume of juice squeezed from a fresh orange (this orange juice contains a reducing sugar) to the Fehling's solution in the test-tube. Place the test-tube in a heated water-bath and observe the various characteristic colour changes within the test-tube before the dark blue liquid becomes brick-red in colour. The red precipitate of cuprous oxide has been formed by the reducing action of the sugar on the copper sulphate of the Fehling's solution.

To test for glucose in a solution, add a little Fehling's solution and boil. A red precipitate as above shows the presence of glucose.

Fehling's test for non-reducing sugars. A non-reducing sugar, such as sucrose in cane-sugar, will not react with Fehling's solution as above it will only do so if the sugar is first boiled with dilute hydrochloric acid, and then made alkaline with caustic soda. This is because the acid first breaks down or hydrolyses the complex sugar into two simple sugars, as shown below.

$$\text{Sucrose} \xrightarrow[\text{acid}]{\text{hydrolysis by}} \text{glucose} + \text{fructose}$$

Test for starch. It is very easy to test for starch. Cut a thin slice of yam and pour a small quantity of aqueous iodine solution on to the cut surface. (*Note:* iodine is not soluble in water, but is soluble in aqueous potassium iodide solution; do *not* use tincture of iodine, that is, iodine dissolved in alcohol, for this test.) A very characteristic blue-black colour is produced when dark, reddish-brown iodine solution is added to starch. Do you agree that yam contains large amounts of starch?

A further test for starch is described in Chapter 31.

Fats and Oils

Fats, like carbohydrates, also contain carbon, hydrogen, and oxygen, but, unlike carbohydrates, the hydrogen and oxygen are not present in the same proportions as in water. Common sources of fats and oils are vegetable oils like coconut-oil, palm-oil, fat meat, butter, nuts, and milk. Fats are solid oils. They are readily oxidized to produce carbon dioxide and water and also set free energy which is transformed into body heat. The amount of heat produced from fats in this way is as much as twice that given by the same quantity of carbohydrates. There is thus no need to eat much fatty food in a tropical climate.

Fats and oils have special biological significance, among which are the following:

(*a*) As fats and oils contain less oxygen than carbohydrates or proteins, they are a highly concentrated form of fuel, one gram of fat

giving on combustion about 9·3 kilocalories of energy.

(*b*) Since fats and oils are not soluble in water solutions, they are readily stored in tissues and are therefore available to meet nutritional deficiencies. An average adult person has a fat content of about 120 grams per kilogram body weight of which more than half is in a stored form.

(*c*) Fat under the skin of an organism reduces loss of heat from the surface of the body.

(*d*) Fats carry in solution many fat-soluble minerals such as Vitamins A, D, and E.

(*e*) Fats delay the rate of digestion in the stomach, and as a result they appear to be more satisfying for a longer time than carbohydrates.

Tests for oils and fats. Many seeds contain part of their food store in the form of oil; this oil is detected by crushing part of—for example—a groundnut seed on a piece of filter-paper. A translucent patch develops on the paper, which is best seen by holding the paper up to the light.

Another very reliable test is to treat the oily food material with *fresh* 1 per cent osmic acid; the result is a black stain. The fumes of osmic acid can be dangerous to the eyes, so take care when performing this test.

Yet another test involves the use of the red dye Sudan III which is soluble in fats. Pour a little coconut or other oil into a test-tube and add a few drops of the red dye Sudan III. Shake well and notice that the oil takes up the red colour. Pour half the coloured oil into a second test-tube. To one tube add water and to the other alcohol. Shake, and when the liquids have separated again notice that the dye has remained with the oil.

Proteins

Proteins contain not only carbon, hydrogen, and oxygen, as in carbohydrates and fats, but also nitrogen and often phosphorus or sulphur. Common sources of proteins include lean meat, white of egg, gelatine, milk, butter, and the seeds of many plants, especially legumes. When proteins are oxidized, they provide energy, as do carbohydrates and fats; but they also supply the material for growth and repair of the tissues of the body. This function is due to the fact that they form the main part of protoplasm (see Chapter 1) which is the 'basis of life'.

Proteins are made up of groups of simpler compounds known as *amino-acids* of which there are about twenty.

There are large numbers of different kinds of proteins. For example, the proteins of beef, mutton, pork, fish, chicken and crab are all distinct. However, they may be put into two classes, called the First and Second Classes.

The First Class (or Complete) proteins are those containing all the amino acids necessary for growth and life. Most proteins from animal sources belong to this class, such as milk, egg, lean meat, fish and chicken. From vegetable sources, green leaves, as well as soya bean and Brazil nuts provide First Class Protein. In view of their importance in growth of the body, it is advisable to take in some such protein daily. However, they tend to be rather expensive.

Second Class proteins lack amino-acids essential for growth but can repair muscular waste. They are commonly obtained from vegetable sources such as most nut proteins or peas and beans. They are not as easy to digest as the First Class or Complete proteins, but they are relatively cheaper.

Test for proteins. The presence of protein in a solution can be shown by adding an equal volume of sodium hydroxide solution and two drops of dilute copper sulphate solution. After shaking gently to mix, a violet colour appears. If the result is doubtful it is useful to set up a control using water in place of the specimen and to compare the colour with that given by the test specimen.

Another test for proteins can be made by using Millon's reagent. (This is a substance containing mercurous nitrate and nitric acid.) When Millon's reagent is added to a substance containing protein, and the mixture is carefully heated, a pink or red colour is produced.

Food Energy and Food Values

Apart from providing materials for new protoplasm, food fulfils an essential function of supplying the body with the potential energy for movement and heat required to keep the body temperature above that of the surroundings.

If a person gives out more energy than he takes in as food, he loses weight by burning up his reserves of fat and his cellular stores of protein. Thus, a person can 'slim' either by taking more exercise or by taking less food. The first is the better way unless, in cutting down fats and carbohydrates, he makes certain that he still continues to take enough proteins and vitamins. If he gives out less energy than the stored energy he takes in as food then, of course, he will gain in weight by storing the excess, mostly as fat under the skin. If you wish to keep your weight without change, you have to make sure that the energy you give out as heat and work is just balanced by the stored energy you take in as food. Elderly people often put on weight because they gradually cut down their exertions, without at the same time reducing their intake of food.

The energy transformed from food by a man can be measured fairly exactly. We measure it as heat, in units called *Calories.* A large Calorie (capital C) or kilocalorie, which we use in biology, is the amount of heat that will raise the temperature of one kilogram (1000 grams) of water by 1°C. The energy *content* of food can be measured thus: A definite weight of food is dried and shut up with compressed oxygen in a steel bomb. The bomb is immersed in water and the food ignited by a wire heated electrically. All the energy of the food is given out as heat and is calculated from the rise in temperature of the water.

By such a method, calculations have been made to determine the energy which the body can obtain, on the average, from 1 gram of protein, fat, or carbohydrate after making the necessary allowance for loss in digestion. Proteins and carbohydrates have been found to yield about 4 Calories per gram each, while fats and oils yield about 9 Calories per gram. These figures therefore make it possible to calculate the energy *value* of a food directly if we know its composition and if it is reasonably digestible.

Examples of some typical tropical foods and the Calories they produce (calorific values) are as follows:

Food	*Scientific Name*	*Energy value (Calories per 100 g)*
Cassava (Manioc)—peeled roots	Manihot utilissima	378–390
Cocoyam—peeled tuber	Xanthosoma sagittifolium	383
	Colocasia esculenta	376
Sweet Potato tuber	Ipomoea batatas	391
Yam Tuber—peeled	Species of Dioscorea	373–391
Coconut—edible portion	Cocos nucifera	691
Groundnut seed	Arachis hypogea	605
Maize	Zea mays	410
Rice	Oryza sativa	395–397
Soya Bean	Glycine max	452
Water Melon	Citrillus vulgaris	576–658
Banana—ripe peel and edible portion	Musa sapientum	384
Plaintain—unripe peeled	Musa sapientum var. paradisiaca	392

Some useful information on the nutritive status and use of some of these tropical foods is provided at the end of this chapter.

Energy required by man under different conditions

The number of Calories needed by the body at any time depends on the amount of energy it uses in work. Calculations show that the average man doing average work has to obtain about 3,000 Calories of energy daily from his food. If he is doing heavy manual work, he will be using up more energy and will need to take in rather more calories. In the case of a wood-cutter, up to about 5,000 Calories per day are required. On the other hand, a man lying in bed all day needs fewer Calories and it is estimated that he still requies about 1,700 Calories a day. This is mainly used up for the work of his heart, breathing organs, and to keep up his body temperature. In the cooler months of the year he must generate more heat, and will therefore require rather more energy than in hotter periods of the year.

The following shows a comparison of energies required by a man under different conditions:

Resting in bed	0·94 Cal/min
Walking	4·9
Chopping wood	6·7
Cycling	6·6
Standing still	1·8

Mineral Salts

Normally, the food taken in by animals contains mineral salts, but certain salts which are used for specific purposes in the body are needed in larger quantities than is obtained from the foodstuffs, so that extra quantities of these are often added to the normal diet. Some of these salts are sodium chloride (common salt), calcium, and iron salts.

Sodium chloride is present in the blood of all animals and since some of it is lost through sweating, it is necessary to add some salt to food. This is particularly important in the tropics where people sweat a great deal to keep cool. Calcium salts are used in the building-up of bones and teeth. Expectant mothers and children need much more calcium because of the rapid formation of bones and teeth, and they often have to take calcium tablets. Common sources of calcium include bones of the animals we eat, milk, and cheese.

Iron is an important ingredient in the red colouring matter called *haemoglobin* in the blood-corpuscles. Iron is commonly obtained from meat and vegetables such as beans and peas. It is not present in larger quantities in plantains than is normal in other fruits, as is sometimes thought.

Vitamins

One very important group of accessory substances, existing in very small quantities along with some of the food substances we take in, are called *vitamins*. They contribute a great deal to the maintenance of our health, and when they are absent from our diet we suffer certain *deficiency diseases*. These diseases have been known for many years but it was only in the present century that the vitamins were discovered and their role in these diseases became known. A number of vitamins are now recognized and these have been named alphabetically, with sub-divisions in some cases.

Vitamin A is a fat-soluble substance which is formed in animal fats, milk, and butter as well as in many yellow fruits such as the mango. Its absence from a diet can cause a type of blindness first recognized in Denmark during the First World War, when a number of the people had no supply of fresh milk or butter.

Vitamin B_1 deficiency was first recognized in Japanese seamen who fed mainly on polished rice. This causes a deficiency disease called *beri-beri*. It occurs in certain parts of the tropics. The disease is prevented by eating unpolished rice instead of polished rice, and brown bread instead of white bread. Vitamin B_1 is known to be present in the outer layer of seeds and also in yeast, milk, egg-yolk, and liver.

Vitamin C is present in fresh leaves and lemon juice, and in many uncooked fruits and green vegetables, but is destroyed by boiling. Its absence causes a deficiency disease called *scurvy*.

Vitamin D, which enables calcium to be absorbed, is found chiefly in cod-liver oil. Its absence causes *rickets*, which results in bow legs and similar signs of soft bones in children.

Vitamin E, which is present in the outer layer of seeds, in green vegetables, and in eggs, has been found to be essential for the reproduction of animals such as rats.

Finally, *Vitamin K* is present in green vegetables and promotes clotting of blood.

It is obvious from this brief account of vitamins that fresh and natural food is vital for healthy life.

Below is a table which summarises the sources, daily dosage, and functions of the vitamins:

Vitamin	Sources (from food)	Daily Dose	Function
A	Storage fats of liver such as fish-liver oils, fat of milk, cream, and butter. Also in some yellow fruits such as the mango and yellow maize. In green leaves and red palm-oil.	1–3 mg	Promotes normal growth of young animals and maintains growth of certain adult tissues.
B_1	Outer layer of seeds as in unpolished rice or maize, and also in yeast, milk, egg-yolk and liver, beans, and nuts.	1–3 mg	Prevents a deficiency disease known as beri-beri in man; absence can cause exhaustion in birds, also impairment of appetite.
C	Fresh leaves, citrus fruits, lemon juice; also in many uncooked fruits, e.g. banana, green vegetables tomatoes and onions.	25–75 mg	Prevents a deficiency disease called scurvy. Helps wound repair and regrowth of bone tissues. Prevents disorders in teeth growth.
D	Associated with Vitamin A in distribution. Cod-liver oil and other animal fats including egg-yolk and butter, also cocoa-butter.	1 mg	Regulates calcium to be absorbed from intestine in the body for building strong bones. It also regulates metabolism of calcium and phosphates in the body.
E	Outer layer of seeds, in green vegetables including lettuce and in eggs, as well as cotton seed oil	10–50 g during pregnancy. For males and non-pregnant females, unknown.	Prevents abortion, and sterility.
K	Green vegetables.	Not known	Promotes normal clotting of blood.

Balanced Diet

In terms of energy requirements, not only must the energy value of the diet be adequate, but the three main classes of foodstuffs should be present in roughly certain proportions that are found to be conducive to proper health. For an average man, requiring 3,000 Calories daily, a diet containing 70 grams of protein, 80 grams of fat, and 500 grams of carbohydrate is fairly good—provided that at least a third of the protein is animal protein, which provides the various amino-acids in roughly the right proportions for making human tissues. Children, nursing mothers, and expectant mothers, need a good deal of animal protein, which can be obtained from meat, fish, eggs, or milk products. In terms of typical foodstuffs in the tropics, it is estimated that a balanced daily diet per person should have the following weights in ounces of the different foods; 14 of cereals, 3 of pulses, 4 of leafy vegetables, 3 of root vegetables, 3 of other vegetables, 3 of fruits, 10 of milk, 2 of sugar, 2 of fats and oils, 2 of fish, 1 of meat and one egg.

The composition of the various foods which we usually eat shows us that we cannot hope to get all the essential food substances, proteins, fats, carbohydrates, mineral salts, water, and vitamins, from only one particular food. Moreover, we need to take these substances in the right proportions in order to maintain good health, and when this is achieved, the diet is described as being *balanced*. Such a diet should, broadly speaking, contain about 50 per cent of carbohydrates, from 25 to 30 per cent of fats, and about 10 to 25 per cent of proteins. The vitamins and mineral salts form only a very small proportion, but a lot of water or liquid is important for the body.

As has been mentioned before, in many tropical diets there is far too much carbohydrate, far in excess of the 50 per cent normally expected, while the proportion of protein is too low. Such diets are clearly not balanced. This is largely due to the fact that foods containing proteins are expensive, while carbohydrate foods tend to be the cheapest. With such low standards of living in many under-developed countries in the tropics, most people cannot afford the expensive protein foods; yet in actual fact there are a number of relatively cheap foods in the tropics which contain a lot of valuable food substances.

Malnutrition

Poor or ignorant people tend to feed themselves and their children on cereals as a source of cheap calories. Thus although carbohydrates provide cheaper sources of calories, they do not offer the required nourishment and so too much of it readily results in malnutrition since persons living so much on carbohydrates get too little first class protein, calcium, and vitamins A, C, and D in their meals.

Apart from too much carbohydrate, malnutrition may also be caused by lack of food containing animal products such as meat, milk, or fresh fruits and vegetables. Protein deficiency in children results in the disease known as *Kwashiorkor*. In addition, malnutrition may result from a combination of such conditions as bad home surroundings and neglect, lack of fresh air, overcrowding in sleeping conditions, insufficient sleep, and habitual uncleanliness.

Malnutrition shows as chronic fatigue, loss of interest in work, inability to concentrate, and poor spirits although muscular efficiency may still be unaffected. We have seen above that it leads to different types of deficiency diseases. It should be noted that indiscriminate taking of medicine is no substitute to the fundamental needs for health which are balanced diet, fresh air and sunlight, exercise, rest, and cleanliness.

SUGGESTED PRACTICAL WORK

1. Test for food substances present in a meal of rice, beans, and red oil, or any one of the common local meals.

2. Consult your lunch-time menu for the week. Each day, make an estimate for the proportion of each of the food substances in the meal. Examine your analysis and state, giving reasons, whether each menu constitutes a balanced diet or not.

3. A piece of beef is shown to contain 4·2 gm. of protein and 8·0 gm. of fat per ounce. Calculate the total energy content in terms of Calories per ounce.

Nutritive status and use of some tropical foods.

1. **Cassava** (*Manihot utilissimus*)

Cassava is also known in some tropical countries as Manioc, Tapioca root, Brazilian arrowroot.

Cassava is used in a number of tropical countries as a cheap source of carbohydrate food for man and livestock. It is either cooked or grated and roasted into flour and taken under the name of 'gari'. In its raw state, cassava contains hydrocyanic acid which is poisonous, but this poison comes out of the cassava when placed in water, a feature of indigenous handling of cassava.

Gari is low in protein, oil, ash, and crude fibre, but it is a valuable source of carbohydrates. Since the preparation of gari ensures that it is free from hydrocyanic acid, it is without doubt a valuable source of energy in the rations of all classes of livestock, particularly during the dry season. However, it needs supplementation with a fair amount of protein and vitamin-rich concentrates.

Cassava in its raw or cooked state is widely used to feed swine, cattle, sheep, and goats, but here again the animals do better if the cassava is balanced with protein-rich foods, and the quantity of uncooked cassava in the ration should preferably not be more than fifty per cent of the dry matter, otherwise the pigs may show unthriftiness and their growth rates may be retarded.

The residues or waste produced from cassava starch or tapioca processing are used in feeding livestock in many parts of the world.

Peels of cassava roots, like most other roots and tubers, are much richer in proteins than the edible portion. This part is a fairly good source of nutrients and is a valuable waste product to feed sheep, goats, and cattle.

Cassava leaves are much richer than any other part of the plant in proteins and oil, and are a fair source of carbohydrate. The leaves are well relished by all classes of livestock.

2. **Cocoyam** (*Xanthosoma sagittifolium* or *Tania* and *Colocasia esculenta* or *Taro*)

The tubers of these plants have a higher content of crude and true proteins than cassava; they are exceptionally rich in ash, low in fibre, and form a fair source of oils and fats. In this respect, *taro* seems slightly superior to *tania* in its content of crude and true proteins, although the latter is richer than the former in mineral elements. The ash seems to be concentrated more in the peels of *taro* corms, while it appears to be more evenly distributed throughout those of *tania*.

The outer peels of the corms, which contain a fairly high proportion of crude and pure proteins, are richer in oil than the carbohydrate fleshy portion. The peels therefore constitute a valuable food for ruminants and other livestock.

The leaves of these cocoyams contain more crude and pure protein and oil than most leaves of root crops. It is therefore not surprising that they are frequently eaten by sheep, goats, and cattle; and this is possibly also due to the high percentage of ash in these leaves which may make them more palatable. The leaves are also used for feeding livestock.

The young leaves are taken in some tropical countries as spinach, since they are a valuable source of minerals and vitamins.

Cocoyam contains an acrid substance which is irritating to the digestive tract and may even prove poisonous. Therefore it should be cooked before it is fed to livestock, since cooking removes this substance.

3. **Sweet potato** (*Ipomoea batatas*)

Sweet potato tubers are a valuable source of nutrients. They contain, on dry matter basis, about 5 per cent crude protein, and 3 per cent ash. They are rich in carbohydrates, and contain a fair source of fat.

The proteins of sweet potato are of high biological value since they are made up of many essential amino acids. It is a good source of certain of the B vitamins and also vitamin C.

Sweet potato tuber has a higher percentage of dry matter, starch, sugar, and fat than the European Irish potato and compares well with it in protein content.

From its chemical composition and qualitative nutritive value, the sweet potato seems to deserve better attention than it is accorded now, as a source of readily digestible and soluble carbohydrates not only for man but also for livestock in tropical countries.

The young leaves of sweet potato provide a good source of green vegetable for man. They are much relished by cattle, sheep, and goats. The leaves are a valuable source of protein (about 25 per cent), ash (about 10 per cent), oil (about 4 per cent), but low in crude fibre (9 per cent).

The vines of sweet potato last throughout the dry season, and so should be of value for feeding ruminants and other livestock during that period when grazing is scarce.

4. **Yam** (*Dioscorea*)

The yam is a useful source of good quality starch. It is rather expensive and therefore used more by man, but could otherwise be used in

feeding livestock. The peels of yam are a fair substitute for feeding livestock.

Some yam varieties are relatively richer in protein and sugar but these are unfortunately less mealy and palatable when boiled. When yam is stored for long, the water and starch content decreases, the latter being converted to sugar, particularly when young shoots begin to appear. This makes the yam tubers rather soggy and less tasty.

5. **Maize: Indian Corn** (*Zea mays*)

Maize is a widely used food in tropical countries. The fresh grains are eaten roasted, or boiled on the cob. The grains are sometimes cooked in combination with pulses or milled and boiled as porridge.

In many tropical countries, maize offers a fairly cheap source of feeding-stuff in the development of livestock production. It offers a relatively cheap source of food for the pig industry. It is much liked by poultry, the local fowl being raised practically on maize grains.

6. **The Banana** (*Musa sapientum*)
The Plantain

Both the plantain and the banana are important sources of carbohydrate for man, the plantain being cooked and used as a vegetable while the ripe banana is eaten as fresh fruit.

Both are relished by livestock, particularly the sheep and the goat. In addition, the peels, more especially those of plantain, constitute valuable fodder for sheep and goats.

Banana is not a rich source of protein. The amount of this nutrient in the fresh weight varies between 1·3 to 1·6 per cent. The protein content is about 4 per cent in both the ripe and unripe fruit, although substantially higher in the peels. It is also noteworthy that the protein content in the ripe banana and plantain is somewhat higher than in the unripe ones.

Bananas are high in potassium, magnesium, sodium, and phosphorus; they are a fair source of calcium and iron and contain traces of copper, iodine, manganese, zinc, and cobalt.

The starch and total sugar content of the peel were found to be much smaller than those of the pulp.

The peels of both the ripe and unripe plantain and the banana contain relatively more protein than the edible portion. In the case of the banana, the total crude protein is somewhat richer in the ripe than in the unripe fruit, a condition well reflected in the peels. No appreciable difference in the plantain is observed in this connection.

The nutrients contained in them become more easily digestible by livestock if the peels are obtained from the ripe fruits. The peels are low in crude fibre and are rich in mineral matter, carbohydrates, and certain of the vitamins. If milled, they can be incorporated in livestock rations.

7. **The Coconut** (*Cocos nucifera*)

Coconut provides one of the best sources of good quality oil. This is extracted from copra—the dried fleshy kernel or endosperm of the fruit. Copra contains between 60 and 72 per cent oil, which is widely utilised for edible purposes, for cooking, for making margarine, or for the manufacture of soap or candles.

Copra oil and palm kernel oil are similar and often interchangeable in cooking and manufacturing processes.

After oil extraction, the cake residue provides a valuable feeding-stuff for livestock.

Coconut is fairly rich in protein and oil, somewhat high in crude fibre, but low in ash. Coconut is also rich in carbohydrates, a high proportion of which are sugars and cellulose with only negligible amounts of starch. It is poor in minerals, containing mainly sodium chloride with traces of potassium chloride and magnesium chloride.

8. **The Oil Palm** (*Elaeis guineensis*)

Palm kernel provides another common source of oil. The oil is light yellow in colour and resembles coconut oil in taste and odour. It is, however, easily hydrolysed and this makes it go rancid in a shorter time. It is a good source of edible oil, and is used also for margarine, soap making for medicinal purposes, and as hair oil.

After extraction of the oil, the residue, which is the cake, does not contain as much protein as groundnut cake, but it can be used for dairy and fattening cattle, for pigs, and for horses. Unlike groundnut cake, palm kernel cake produces a butter and body fat of firm consistency.

9. **Groundnut** (*Arachis hypogaea*)

The groundnut has a high protein content and is widely used in many parts of the tropics where its nutty, agreeable flavour makes it a particularly suitable vegetable food when roasted or cooked, and mixed with maize.

As a food, groundnut is one of the most concentrated products, since one gram supplies 6·03 Calories and provides a higher value of nutrients than any of the other feeding-stuffs.

The groundnut has a relatively low content—under about 10 per cent—of carbohydrate, mainly starch and sucrose, but the nut has a relatively high content of fibre.

After extracting the oil from the nut, the residue cake is richer in protein than the whole kernel and forms a most valuable cake for livestock.

10. **The Soyabean** (*Glycine max*)

The seeds of soyabean are used as food by man, or as a concentrate for farm animals. Oil is extracted from them aud they are also used in the preparation of a number of edible substances. In addition it is used for silage to supplement maize as a feed for livestock owing to its high protein content.

CHAPTER SEVENTEEN

The Alimentary Canal and Digestion of Food in Mammals

THE food we eat passes through a long, more or less convoluted tube (about 7 metre long in man) called the *gut* or *alimentary canal* (Fig. 17.1). This canal begins at the mouth, through which food enters the body, and ends at the anus, through which the waste remains of the food leave the body. The complex food substances, like carbohydrates, fats, and proteins, cannot enter the tissues of the alimentary canal, and so have first to be broken down into simpler, soluble substances, whose molecules are small enough to diffuse through the walls of the alimentary canal and finally into the tissues of the body. This is the main purpose achieved by passing the food through the alimentary canal. The process which brings food substances into solution, ready for absorption, is called *digestion.* Thus the aim of digestion is to prepare the food for absorption.

Digestion is aided by certain substances called *enzymes*, produced by specialized living cells at specific parts of the alimentary canal. These enzymes are organic catalysts. As catalysts they are present in very minute quantities and yet can speed up the rate of reaction of large quantities of substances. This is possible since the enzyme itself remains unchanged at the end of the reaction which it catalyses. Enzymes are more or less specific with regard to the substances on which they will act. Thus the enzymes which help in the digestion of food may be classified into (*a*) carbohydrate-splitting enzymes such as *ptyalin*, (*b*) protein-splitting enzymes such as *pepsin*, and (*c*) fat-splitting enzymes such as *lipase*. They are often contained in digestive juices produced by digestive glands. The action of the enzymes ptyalin, rennin, and pepsin will be illustrated later.

The Passage and Digestion of Food

The Mouth. Man takes in food at the mouth with the aid of his lips and teeth, particularly the incisors. The food is then chewed and ground up by the molars. By breaking the solid food into small pieces in this way, a larger surface area is created for the action of the enzymes which are present in digestive juices of the alimentary canal. The first such action begins in the mouth during the process of grinding the food, when it is mixed with *saliva*, a slightly alkaline digestive juice produced by the salivary glands. This juice contains the enzyme ptyalin, which speeds up the rate at which cooked starch is changed into sugar (maltose). This digestion of starch, which starts in the mouth, continues until it is completed in the stomach and the small intestine. Sodium chloride increases the activity of ptyalin as will be shown later on.

The Stomach. The food, moulded into a ball by the tongue, passes from the mouth via the throat and gullet to the stomach where it remains for several hours. Here, a digestive juice, the *gastric juice*, is

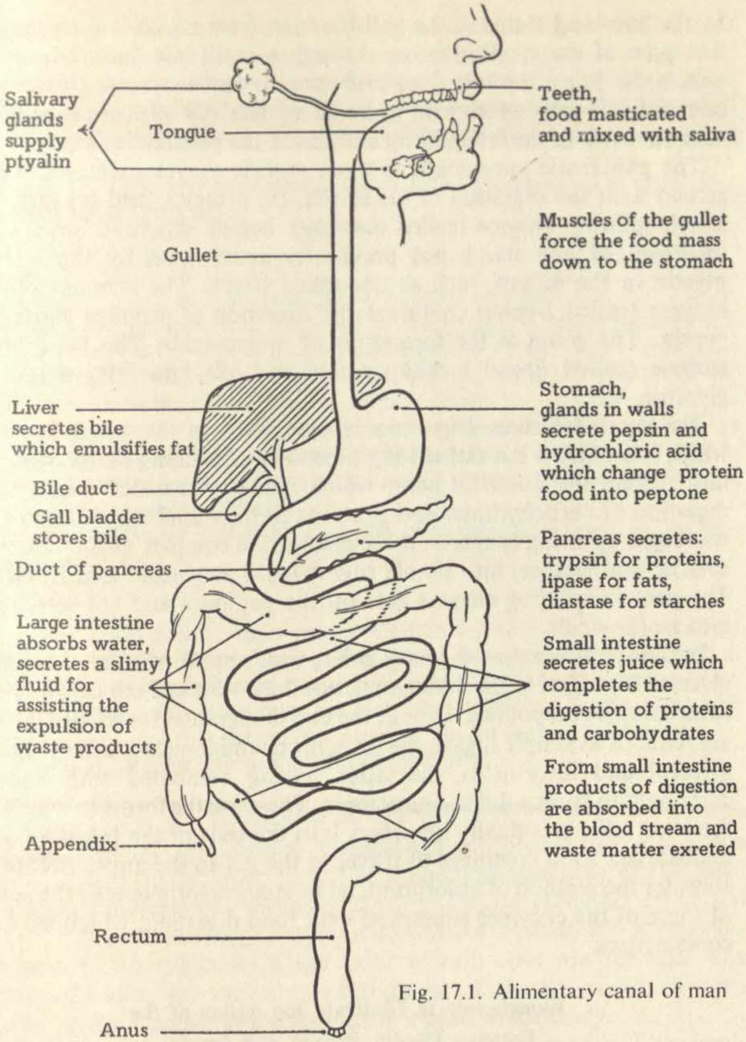


Fig. 17.1. Alimentary canal of man

secreted by glands in the stomach-wall and mixes with the food. This juice is strongly acid, containing hydrochloric acid; it kills bacteria and thus stops the food from decaying. It also begins to neutralize the alkaline saliva. Two enzymes, *pepsin* and *rennin*, are present in the gastric juice. Pepsin begins the digestion of proteins into soluble peptones, while rennin acts on the protein in milk, causing it to clot and allowing pepsin to act on it. The food, now virtually in a liquid state, passes gradually from the stomach to the duodenum through a ring of muscle between these two chambers.

The Duodenum. In the first part of the small intestine, the duodenum, the acidic food meets two digestive juices, both of which are alkaline and which thus neutralize it. These are the *bile* from the liver and the *pancreatic juice* from the pancreas. The bile is a greenish fluid secreted

by the liver and stored in the gall-bladder, from which it runs into the first part of the small intestine through a small bile-duct. Unlike the pancreatic juice, the bile does not contain any enzymes. However, it contains bile-salts which help to break up fats and oils into droplets to ease the work of the fat-splitting enzyme in the pancreatic juice.

The pancreatic juice contains three specific enzymes which are concerned with the digestion of (*a*) starch, (*b*) proteins, and (*c*) fats. The starch-splitting enzyme (called *diastase*) begins digestion into sugar (maltose) of any starch not previously acted upon by the enzyme ptyalin in the mouth, such as uncooked starch. The protein-splitting enzyme (called *trypsin*) continues the digestion of proteins started by pepsin. The result is the formation of amino-acids. The fat-splitting enzyme (called *lipase*) breaks up fats and oils into fatty acids and glycerol.

The Small Intestine. Digestion is completed in the small intestine, which is a narrow but rather long tube. The cells lining its internal surface secrete the *intestinal juice*, which contains enzymes which carry digestion of carbohydrates and proteins to their final stages. There are two sugar-splitting enzymes; these change the complex sugars (such as sucrose and lactose) into simple sugars (such as glucose and fructose). The protein-splitting enzyme acts on the peptones and converts them into amino-acids.

In the small intestine the fatty acids, which are formed together with glycerol from fats in the duodenum, combine with sodium carbonate to form soluble compounds. Thus at the end of digestion the carbohydrates are reduced to simple sugars, the proteins to amino-acids, and the fats to glycerol and fatty acids, the latter having combined with sodium carbonate to form soluble compounds. These are the forms in which the food we take in is finally absorbed into the cells of the intestine. Any unabsorbed food continues to travel in the gut to the anus. Before we consider the method of absorption, let us study experimentally the action of some of the enzymes concerned with food digestion, which we have come across.

Experiments to Illustrate the Action of the Enzymes Ptyalin, Rennin, and Pepsin

Ptyalin

Method. First prepare a solution of saliva. Warm about 50 cc of water in a beaker to about 37° C. Then use some of this water to wash your mouth free of any pieces of food. Next take about 20 cc of the water into your mouth and hold it there for a minute or more while keeping it moving all the time. This will make a solution of saliva. Pour this solution into a clean beaker and filter it. Also make a 1 per cent solution of starch. Mix equal quantities of the saliva and starch solutions in a test-tube. Shake up the mixture and put it in a water-bath at 37° C. (body temperature). In a second tube mix starch solution with distilled water instead of enzyme. Make a test of the changes in these mixtures every 30 seconds, by adding a drop of iodine solution to a drop of the mixture on a tile. A blue colour demonstrates the presence of starch, a purple or reddish colour shows the presence of dextrin (an intermediate substance in the hydrolysis of starch), while a colourless reaction shows the absence of starch or dextrin, though the sugars to which starch is digested by ptyalin are present. The test should be continued

until this negative reaction is obtained in the tube containing enzyme. It is not obtained in the other tube; digestion only occurs when the enzyme is present.

If at this stage an equal volume of Fehling's solution (A and B) is added to the remaining mixture and heated in a boiling water-bath, it will be found that a red precipitate, which demonstrates the presence of a reducing sugar, is formed.

Conclusion. The enzyme ptyalin in saliva begins the digestion of starch to a reducing sugar (maltose).

Pepsin

Method. To 4 cc of 1 per cent pepsin solution in a test-tube, add 1 cc of 1 per cent hydrochloric acid. Then put in the mixture a small piece of fish muscle. Place the test-tube in a water-bath at about 37° C. Shake it from time to time, and it will be found that as the pepsin digests the protein of the muscle, the latter gradually dissolves. In a control tube, with no pepsin, this does not happen. To ascertain that the solution contains protein, use half the mixture for a protein test (see page 157). The presence of half-digested protein can then be tested for by adding about 1 cc of 1 per cent bile-salt solution. A white precipitate will be formed.

Conclusion. Pepsin begins the digestion of proteins into intermediate substances (peptones).

Rennin

Method. Add about 1 cc of rennin solution to about 5 cc of fresh cow's milk in a test-tube. Shake well, and place the test-tube in a water-bath at about 37° C. A clot will be formed in the mixture in about 5 minutes' time. On turning the tube upside-down the clot will not flow out. Again, show by a control experiment that the enzyme must be present for a clot to form.

Conclusion. Rennin causes the clotting of milk.

Absorption of Digested Food

Absorption is the diffusion of digested food through the wall of the intestine into the blood-stream. The internal surface area of the small intestine is increased by means of small finger-like processes called *villi* (Fig. 17.2), each of which contains a network of capillary blood-vessels. These are situated beneath the layer of cells covering the villi. The centre of a villus is occupied by a blind tube called a *lacteal*, which is one of the starting points of the *lymphatic system* in the body.

The digested food first enters the cells covering the villi. The simple sugars (digested carbohydrates) and the amino-acids (digested proteins) proceed directly into the blood-capillaries of the villi. They then enter the veins of the villi which, on leaving the villi, join together to form the single large *hepatic portal vein*. This vein carries the food substances to the *liver* where it divides again into capillaries.

The digested fats (fatty acid compounds and glycerol) do not follow the course of the simple sugars and amino-acids as described above, but enter the *lacteals* of the lymphatic system. Here the glycerol and the fatty acids recombine to form once again tiny droplets of fats. The droplets in the lacteals are carried into large lymph-vessels, which in the end send them to a particularly large vein below the neck. From here the droplets join in the general circulation of blood round the body. As we have stated above the sugars and amino-acids first enter the liver before joining the general circulation in the body. The

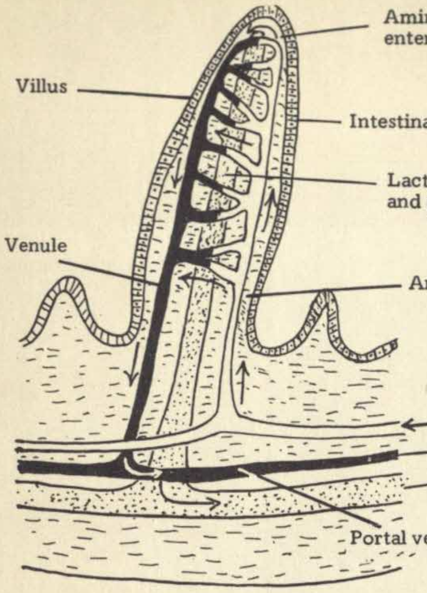


Fig. 17.2. Villus

release of these substances to the blood is controlled by the liver, so that only the required amount enters the general circulation by the *hepatic vein.* The excess sugars are converted into glycogen (animal starch) and stored in the liver until needed, when they are reconverted into sugars which pass into the blood. In the case of the amino-acids, any excess may be converted into a quite harmless substance called *urea,* which is removed from the body, or converted into other substances which can be reconverted into glucose when necessary. We notice that the liver, apart from producing bile, has these two other important functions.

Assimilation. The blood carries the absorbed food substances to the tissues of the body, which assimilate them, or take them in. With the aid of oxygen carried in the blood, the food substances are oxidized by respiration to provide energy for vital activities or to build up new protoplasm for growth.

Elimination of Undigested Residue. After practically all the digested food has been absorbed in the small intestine, the undigested and indigestible residue proceeds to the *large intestine* together with large quantities of water. In the large intestine of man water is absorbed from this residue, leaving the semi-solid *faeces* which collect in the rectum and are passed out through the anus. Herbivorous mammals have a blind projection of the large intestine in which bacteria convert the cellulose in grass into simple sugars, some of which are then absorbed.

SUGGESTED PRACTICAL WORK

1. *Enzymes in digestion.* Carry out the experiments described in the text for demonstrating the action of the digestive enzymes ptyalin, pepsin, and rennin.

2. *Plant enzyme.* The action of a protein enzyme in plant material can be shown as follows. Mix the juice from the leaves and unripe fruit of a pawpaw with some well-minced meat. Note the effect after a few hours.

3. *Alimentary canal.* Your teacher will dissect a rabbit, a rat, a guinea-pig, or some other mammal to show you the parts of the alimentary canal. Make a clear, well-labelled drawing of it, with special reference to all the glands associated with digestion.

Compare and contrast the appearance of the caecum and appendix of a herbivore and a carnivore. How is the size and shape of these organs related to the diet of the animal?

CHAPTER EIGHTEEN

The Blood and its Circulation

WE found in the previous chapter that the digested food substances are carried by the blood round the body in the blood-stream, so that when they are oxidized the heat energy released thereby is made available to all parts of the body. Thus in order to be useful to the body, the blood must keep moving round all parts of the body, and this is known as *circulation*. If circulation stops death follows since the tissues of the body are unable to obtain the oxygen necessary for respiration.

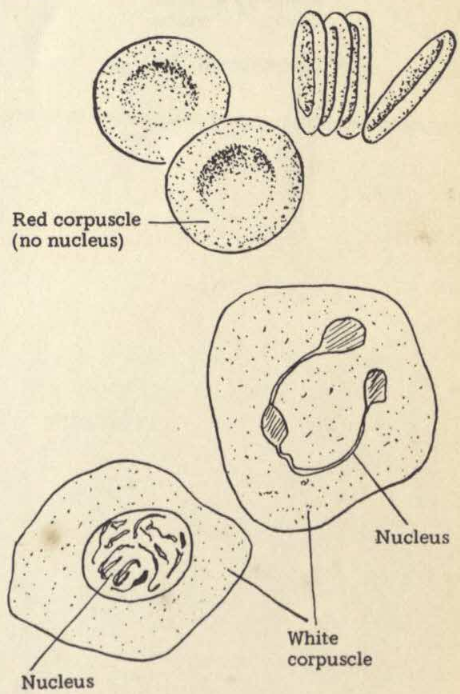
Structure of the Blood

Before considering the course of the blood in the body, we should first examine the structure of the blood to discover more about its functions in the body.

The blood of vertebrates consists largely of an almost colourless fluid called the *plasma*, in which are cells. These are of two main kinds—the *red* and *white corpuscles* (Fig. 18.1). The red corpuscles are rather small, rounded, bi-concave discs, which in the mammals do not possess nuclei. They play a most important role in carrying and distributing oxygen, and they do this by means of a pigment, *haemoglobin*, which is responsible for the red colour of the corpuscles. This pigment takes up oxygen in chemical combination in the lungs to form a compound known as *oxyhaemoglobin*. When the corpuscles reach a part of the body with a lower concentration of oxygen, the oxyhaemoglobin gives up its oxygen to such tissues, and becomes ordinary haemoglobin.

The white blood-corpuscles have an irregular outline and may have a lobed nucleus. They perform very important functions in the body, although their number is small compared with the red corpuscles. They are virtually the soldiers of the body, in that they are able to get rid of bacteria which enter our body tissues, by engulfing and feeding on them. In this manner they resemble *Amoeba*.

Fig. 18.1. The red and white blood-corpuscles



Functions of the Blood

In the course of our descriptions of digestion and the structure of the blood, we have come across a few of the functions which the blood fulfils in its circulation round the body, but we are now to consider all the functions as a whole. The main functions are:

1. *To transport food including vitamins.* Digested food and vitamins are absorbed from the small intestine into the blood, which circulates until it reaches the tissues requiring it.

2. *To carry oxygen.* The haemoglobin of the red blood-corpuscles absorbs oxygen from the respiratory organs and carries it to the tissues to oxidize the absorbed food substances.

3. *To protect the body against disease.* The white blood-corpuscles get rid of bacteria as they enter the body. In doing this the blood also

carries in the plasma certain antibodies which help to kill the bacteria.

4. *To transport chemical regulators*. Hormones from ductless glands (Chapter 20) are carried in the plasma to the tissues for the control of a number of body functions.

5. *To maintain the temperature of the body*. Heat energy is transported from tissues (like the muscles which do a lot of work) to the skin and other parts to help in regulating the temperature of the body.

6. *To get rid of carbon dioxide* produced in the tissues as a result of respiration.

7. *To carry waste products*. These result from the digestion and use of proteins, and are carried to the liver, where they are converted into urea. Finally the blood conveys the urea to the kidneys, which remove it from the body.

8. *To control loss of blood* from wounds and also to prevent entry of bacteria, by means of clot formation.

General Principles of Circulation

The blood of vertebrates is carried in a system made up of the *heart*, *arteries*, *veins* (all of which are the *vessels*), and *capillaries*. Before describing this system in the mammal, we should know something about the general principles involved in the circulation of blood. Before the time of William Harvey, the Englishman who demonstrated the circulation of the blood in 1628, scientists knew merely of the presence of blood in the heart, arteries, veins, and capillaries but were not aware that these formed a closed system (Fig. 18.2). We now know that the heart sends out the blood through the arteries, and receives it back through the veins. In fact, the main purpose of the heart is that of a muscular pump, which by contracting rhythmically (that is, beating) forces the blood along the vessels. The direction of flow of the blood in the heart and vessels is controlled by means of valves.

The arteries are the blood-vessels which carry the blood away from the heart, and the main artery is known as the *aorta*. Because of the considerable force with which the blood leaves the heart the arteries have rather thick and elastic walls. Every time the heart contracts (or beats) to force out blood, the arteries expand momentarily; this wave of expansion which passes along the artery is known as the *pulse*. It is manifested in the regular pulsation which can be seen wherever an artery passes close beneath the surface of the skin, and by the way in which the blood spurts out if such an artery is cut when we are injured. The rate of pulse and heart-beat averages about seventy-two a minute in human beings. This rate is often increased, as a result of exercise or excitement.

After leaving the heart the arteries divide and sub-divide extensively, and their walls become progressively thinner and thinner, until they become the extremely tiny vessels known as the *capillaries* (Fig. 18.3). These capillaries are very numerous and run into practically all the tissues of the body. They have very thin walls through which the digested food substances, oxygen, and waste products diffuse. The substance diffusing in and out of the capillaries first passes through the spaces between the cells or tissues, which are filled with an almost

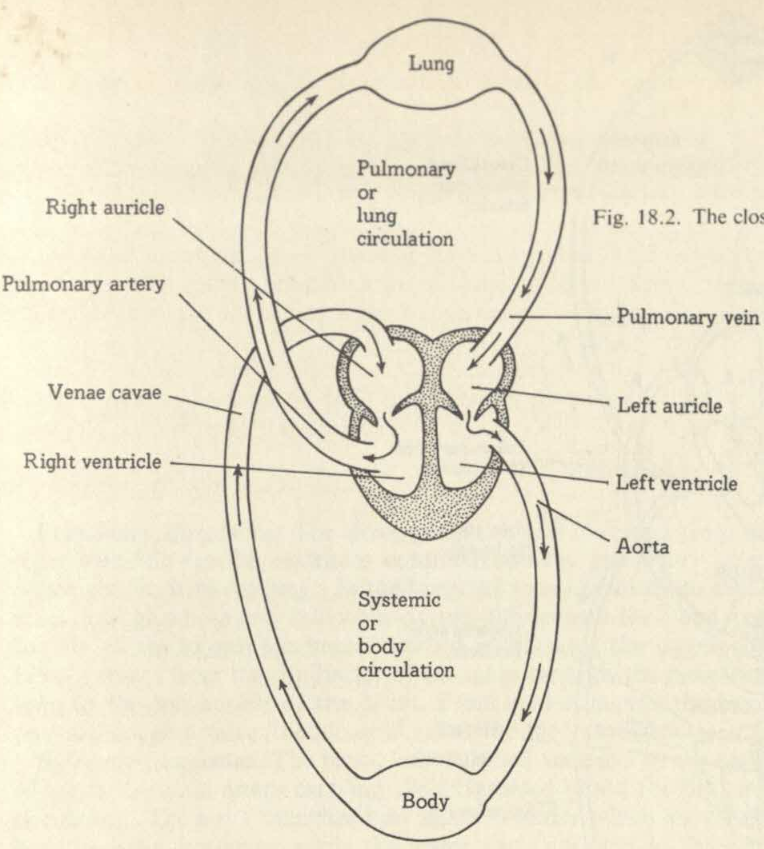


Fig. 18.2. The closed system of blood circulation in mammals

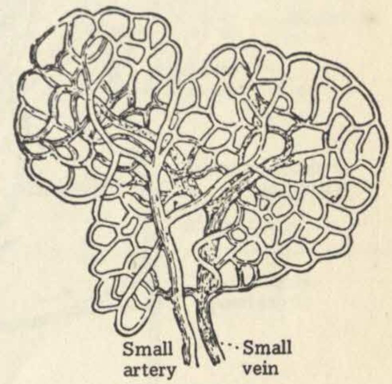


Fig. 18.3. Blood-capillaries

colourless fluid called *lymph*. Basically this is made up of blood-plasma and some white blood-corpuscles. The lymph serves the function of a 'middle-man' between the capillaries and the cells of the body tissues. From the arterial capillaries, the blood begins to make its way back to the heart. It starts by passing from the capillaries of the arteries to the capillaries of the veins, enters small veins, and finally flows through larger veins. It is possible, using a microscope, to see circulation in the capillaries in the web between the toes of an anaesthetized toad.

The veins have much thinner walls than the arteries, and the blood they carry has little or no oxygen and thus looks dark red in colour—very different from the bright red of the oxygenated blood in the arteries. In most cases this deoxygenated blood goes to the heart and then to the lungs to be oxygenated, but some veins do not send their blood directly to the heart but first into some other organ. Such a vein is described as a *portal vein*, and a good example is the vein which carries the blood from the walls of the alimentary canal to the liver, the hepatic portal vein already mentioned.

Circulation in the Mammal

We now have a general picture upon which we can base a detailed description of the circulation of blood in mammals (Fig. 18.4).

Since circulation is associated with the mode of obtaining oxygen for respiration, we find that in the mammals the blood enters the capillaries

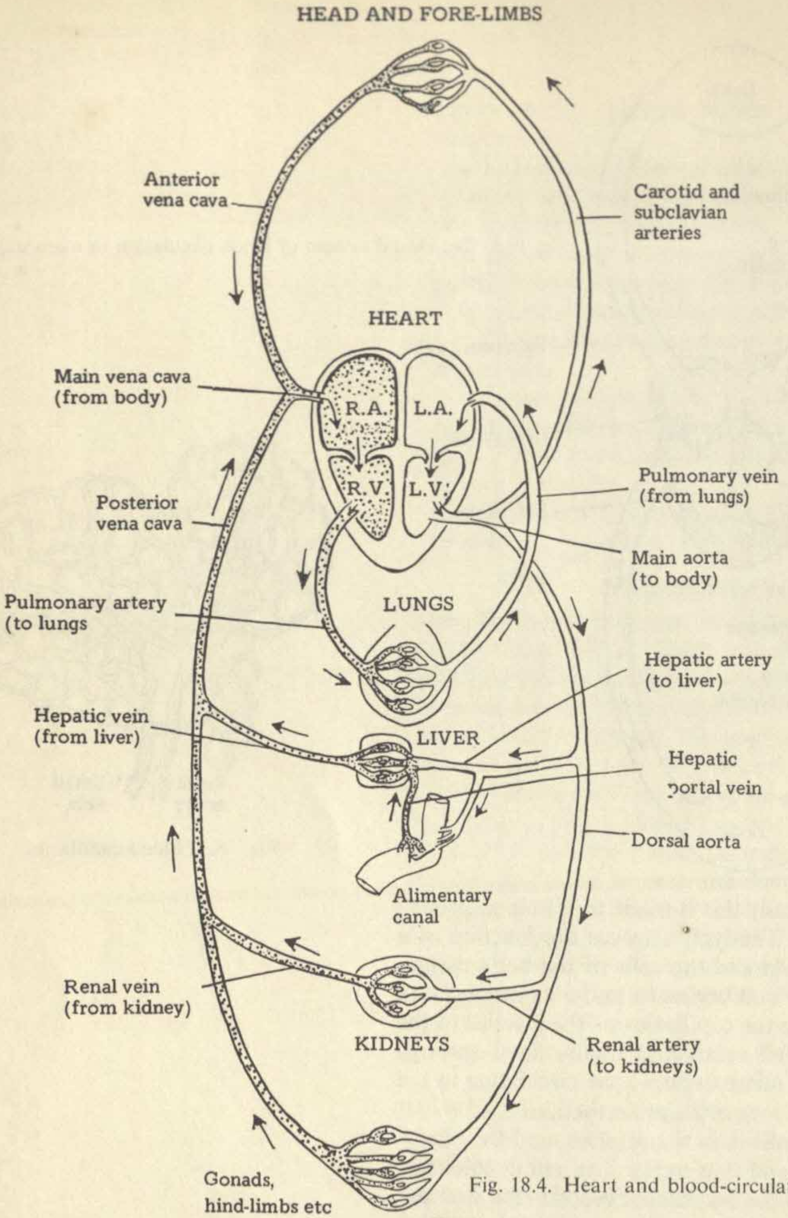


Fig. 18.4. Heart and blood-circulation system in mammals

of the lungs for this purpose. Also, unlike that of the other lower vertebrates such as fishes, amphibians, and reptiles, the heart of the mammal (Fig. 18.5) is split into four chambers (the right and left auricles above, and the right and left ventricles below) with no communication between the two vertical sides. In other words, the right auricle and ventricle are on one side, and the left auricle and ventricle are on the other. Thus the mammal is said to have a *double circulation.* One circulation takes the blood from the heart to the lungs and back to the heart, and is called the *pulmonary*, or *lung*, *circulation*; the other takes the blood from the heart to the various other parts and organs of the body and back to the heart, and this is the *systemic*, or *body*, *circulation* (see Fig. 18.2).

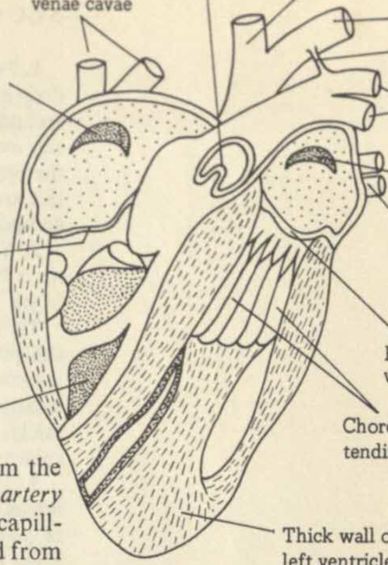


Fig. 18.5. Section through the heart of a sheep

Pulmonary Circulation. The deoxygenated blood is forced from the right ventricle (as the ventricles contract) into the *pulmonary artery* which carries it to the lungs. In the lungs the artery breaks into capillaries through whose very thin walls oxygen diffuses into the blood from the air. When oxygen has been absorbed in this way, the oxygenated blood returns from the capillaries of the lungs through the *pulmonary veins* to the left auricle of the heart. From the left auricle the blood passes through a valve (the *bicuspid valve*) into the left ventricle.

Systemic Circulation. The blood leaves the left ventricle by the aorta, which is the main artery carrying the oxygenated blood for the body circulation. The aorta branches into smaller arteries which supply the head and the fore-limbs, while the major part continues to the main part of the body. The latter artery also sub-divides into smaller arteries which supply blood to the trunk, the liver (the *hepatic artery*), the alimentary canal, the kidneys (the *renal artery*), the reproductive organs, and the hind-limbs. To all these tissues oxygen is supplied by the blood-capillaries which enter them, and carbon dioxide is absorbed from them into the blood. Blood leaves the liver by the *hepatic vein*. The blood from the alimentary canal, as we have indicated above, leaves it by the hepatic portal vein to the liver, and goes from there along the same hepatic vein. Blood in the kidneys is purified by removal of waste nitrogenous products such as urea and leaves the kidneys by the *renal vein*.

After the blood has passed on its oxygen and collected waste-products such as carbon dioxide from the various tissues, it returns to the heart. Three main veins are involved in this return: two of them—the one from the head and the other one from the fore-limbs—unite to form the *anterior vena cava*, while the third, the *posterior vena cava*, returns blood from the hind-limbs, kidneys, liver, and the alimentary canal. The blood enters the right auricle. When the auricles contract the deoxygenated blood from the right auricle is forced past the *tricuspid valve* into the right ventricle. This ends the systemic circulation, for, when the auricles contract again after this, the deoxygenated blood is forced from the right auricle into the right ventricle and when the ventricles contract it leaves the heart through the pulmonary artery to the lungs where it is oxygenated (*i.e.*, pulmonary circulation).

SUGGESTED PRACTICAL WORK

1. Prick the end of your thumb with a sterilized needle to obtain a small drop of blood. Transfer this drop of blood to a glass slide and use the end of a second glass slide to spread the blood along in a very thin film; place a cover slip over part of this blood smear. Examine under the microscope and note the blood-corpuscles. If one of you has a boil or pimple, make a prick near this and examine the blood as above; what is the main difference here in the composition of the two types of blood-corpuscles?

2. Your teacher will dissect a mammal and show you the heart and the main blood-vessels. Note the darker colour of the veins and the paler colour of the thick-walled arteries.

Try also to examine the heart of a larger mammal such as a sheep, and note the parts of the heart and the valves. Which chamber of the heart has the thickest walls? What differences do you see between the bicuspid and the tricuspid valves? Test the strength of the chordae tendineae; do they break easily, or not? Relate these structures to the surrounding walls and to the valves and try to discover how well the chords are suited to their work.

3. Take your own pulse by either (*a*) placing your hand below your left breast or (*b*) placing your right hand on your left wrist, and count the number of beats in a minute. Repeat after running round the school compound. What is the difference and why?

Find the average pulse rate of the pupils in your class (*a*) after a period of sitting down, and (*b*) after a period of energetic exercise. The usual figure given for the average pulse rate is 72 beats per minute; is this true for your class?

4. *Capillary circulation.* Chloroform a tadpole, but not enough to kill it. Then place it on a slide after dipping it into fresh water, and examine the membrane of its tail through a microscope. Note the network of capillaries and the blood circulating through them. Try to follow the movement of the blood from an artery to a vein.

Your teacher could also anaesthetize a toad by immersion for 20 minutes in a 1 per cent solution of urethane, and show you the network of capillaries in the web between the toes.

5. *Pressure points.* There are certain places in the body where arteries run near the surface of the skin—for example, at the wrist, in the 'crook' of the elbow, and beneath the armpit. By exerting pressure in these places (that is, by placing the thumb firmly on the superficial main artery), it is possible to prevent blood from flowing beyond that point. This knowledge is particularly valuable to doctors and nurses and to those interested in first aid. Try to discover more about the subject of pressure points in the human body, and work out how this knowledge may be applied in cases of serious wounds, snake bites, and so on.

CHAPTER NINETEEN

Respiration, Excretion, and Reproduction in Mammals

Respiration

THE essential feature of respiration as it takes place in a great many living things is that food substances are broken down with the aid of oxygen and as a result carbon dioxide and water are produced and energy is released. Much of it takes place within the tissues and is properly called *tissue*, or *internal*, *respiration*. We are more familiar with the movements of the chest and lungs (called *breathing*) which are associated with the taking-in of oxygen and the giving out of carbon dioxide to the outside air. This is *external respiration*. Breathing is thus a mechanical process and by itself has not much to do with respiration proper.

Breathing (Inspiration). Breathing or external respiration consists of two processes, that is, breathing in, or *inspiration*, and breathing out, or *expiration*. The organs concerned with the process of breathing, or external respiration, are the wind-pipe (*trachea*) from which branch the lungs, the ribs, and the muscles between them (*intercostal muscles*), and the diaphragm (Fig. 19.1). All these together with the heart are contained in the chest or *thoracic cavity*, which is lined with a thin membrane, thus creating an air-tight cavity called the *pleural cavity*.

When we breathe in the air passes through our nose, down the throat, and into the lungs. The process involves action on the part of the intercostal muscles as well as the diaphragm, which is a muscular sheet at the base of the thorax and which separates the cavity of the latter from that of the abdomen. The under-surface of the diaphragm is concave when at rest. When inspiration begins the intercostal muscles contract and thus pull up the ribs, which are pivoted on the vertebra. The ribs rise and carry the sternum forwards; at the same time the diaphragm is flattened by contraction of its muscles. These movements result in the enlargement of the pleural cavity of the thorax; and since this cavity is air-tight, its enlargement results in a lowering of the pressure inside it as compared with that of the atmosphere. This leads to an expansion of the thin walls of the tiny air spaces inside the lungs, called *alveoli* (Fig. 19.1). The alveoli are in connection with the outside air so that by their expansion air enters the lungs along the nose or nostrils, trachea, bronchi, and the bronchioles.

Oxygen is taken up and carbon dioxide released across the thin surface layer of each alveolus. The highly convoluted surfaces of the alveoli increase the area over which this process can take place. In fact the area of the internal surface of a pair of human lungs has been estimated to total as much as 450,000 cm^2. Each alveolus is well supplied with blood-capillaries. Oxygen in the inhaled air dissolves in the layer of moisture which lines the alveoli and then diffuses in solution through their thin walls into the capillaries. Here the oxygen combines with

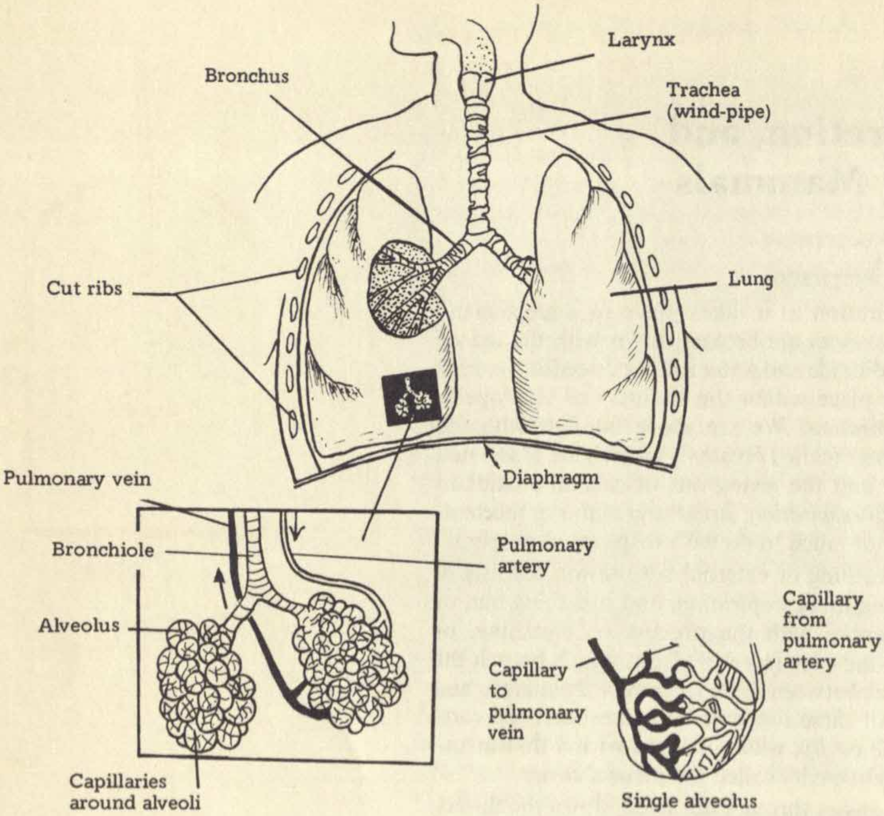


Fig. 19.1. Respiratory organs and structure of the alveoli

haemoglobin in the red blood-corpuscles to form oxyhaemoglobin. As oxygen is entering the blood, carbon dioxide is leaving by diffusion in the other direction. The air in the lungs therefore has an increasing concentration of carbon dioxide and a decreasing concentration of oxygen. It is this change which stimulates us to breathe out.

Tissue Respiration. This is the chemical process by which all living cells obtain energy. In each cell carbohydrates are broken down by oxidation to release carbon dioxide, water, and energy, The equation

$$\text{Carbohydrate} + O_2 = CO_2 + H_2O + \text{Energy}$$

summarizes the reactions which take place. This energy is either used in metabolism or released as heat. The whole process is by no means a simple one.

As a result of tissue respiration the blood in the capillaries becomes deoxygenated. Oxyhaemoglobin breaks down to haemoglobin and oxygen, and the oxygen diffuses from the blood into the lymph and from the lymph into the individual cells. Carbon dioxide diffuses in the opposite direction—from the cells to the blood in the capillaries.

Breathing Out (Exhalation). To breathe air out, the intercostal muscles relax and the ribs are lowered; at the same time the muscles of the diaphragm are relaxed. This increases the pressure inside the alveoli which causes the used air to rush out from the lungs. The expired air

not only contains a high percentage of carbon dioxide, but it is also warmer and damper than the inhaled air. The mechanism of breathing in and out is illustrated by the apparatus in Fig. 19.2. (See Suggested Practical Work below.) It may be mentioned that these breathing movements are imitated when we give first aid to someone who has been nearly drowned or gassed by pushing up and down on his chest.

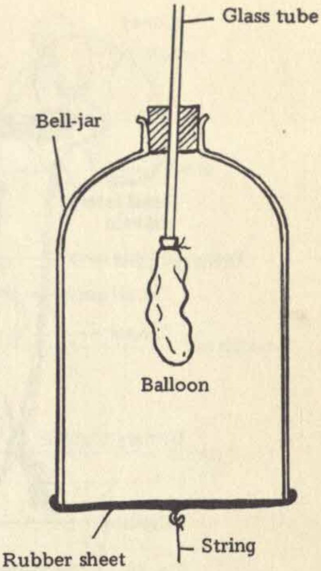


Fig. 19.2. Apparatus to illustrate the mechanism of breathing in and out

Excretion

Broadly speaking excretion means the removal of all unwanted waste matter from the body. But in actual fact the materials concerned are carbon dioxide, water, and nitrogenous compounds, as well as salts which come from the living cells of the body. Faeces passed out of the alimentary canal are not said to be excreted because they are substances which have not in fact entered the living cells, but have only remained outside them throughout the process of digestion.

Carbon dioxide and water are both formed by the oxidation of food material, especially glucose, to set free energy during respiration as indicated above. The main excretory organs in this connection are the lungs, and the carbon dioxide and water vapour from the blood leave the lungs when we breathe out as already described.

Some water and nitrogenous compounds are formed during metabolism of proteins. Some of these compounds are processed in the liver to give urea (a nitrogenous compound of ammonia) and carbon dioxide. The principal organ for removing nitrogenous waste is the *kidney* and we shall have to study this organ in some detail. The sweat-glands in the skin also serve as excretory organs by losing large quantities of water and a little urea and mineral salts in the form of sweat. We have already dealt with this at some length in Chapter 14, where it was pointed out that the evaporation of water from the sweat-glands serves also to regulate the body temperature.

Less water is lost from the skin when the air temperature falls below that of the body, and in such cases the lungs and the kidneys increase their activity in getting rid of the excess water. In mammals with sweat-glands (including man), much water and salt are lost from the skin, especially in the tropics, where they have to drink more water and take more salt in their foods than do those in temperate climates.

The *kidneys* (Fig. 19.3) are the principal excretory organs in all vertebrates. They are found as a pair of bean-shaped bodies attached to the dorsal wall of the abdomen. Inside each kidney are numerous tiny tubes surrounded by fine capillaries which help to absorb the unwanted salts, water, and nitrogenous compounds from the blood and pass them to the ureter. A section of the kidney (Fig. 19.3) shows two well-marked regions. The outer section is called the *cortex* and here the tubes are convoluted; each of them ends blindly in a cup-shaped organ called a *Bowman's capsule*, which surrounds a knot of capillaries, called the *glomerulus*. The inner region is known as the *medulla*, and here the tubes are straighter.

Blood is carried into the glomerulus by way of the renal artery. In the blood plasma are blood colloids (proteins), glucose, amino-acids, urea and other excretory compounds and many types of mineral salts.

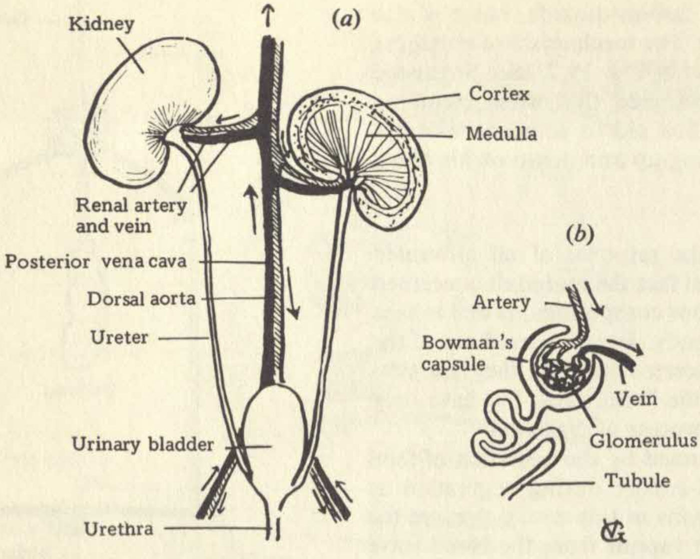


Fig. 19.3. The kidneys: (*a*) a general view; (*b*) detail from cortex

In the glomerulus, these substances are subjected to filtration under pressure between the walls of the capillaries of the glomerulus and the double wall of the Bowman's capsule. As a result, some of the contents in blood pass through minute spaces between the cells. Thus it is the size of the pores which determines which substances can pass through. The filtrate enters the upper end of the renal tubule which leaves the Bowman's capsule, and moves through the tubule under pressure from the Bowman's capsule until it comes to the region of the renal tubule where the latter is surrounded by a network of capillaries. Here re-absorption of some of the contents of the filtrate takes place. The walls of the cells of the tubule in this region are very permeable to all the dissolved substances in the filtrate except urea and the nitrogenous excretory products. The dissolved substances that are removed from the filtrate include glucose, amino-acids and mineral salts (particularly sodium) together with much of the water. Towards the end of the tubule, further re-absorption of more of the dissolved substances takes place. By the time the filtrate reaches the end of the tubule, where the cell-walls are impermeable to water, the filtrate containing urea and other nitrogenous excretory products can be regarded as having the same composition as urine. The urine containing the unwanted excretory products is then passed to the outside via collecting ducts, the *ureters*, *urinary bladder* and the *urethra* which are all more or less impermeable to water.

The difference between the nature of the filtration which goes on in the glomerulus and that which takes place later along the tubule ensures that while unwanted excretory products are removed from the blood, the water and mineral salt content of the blood is also regulated in such a way that any excess can be removed from the blood. The resulting mixture forms the urine.

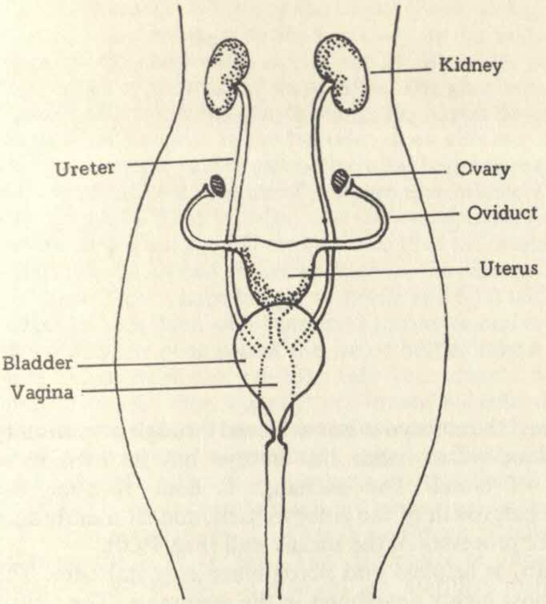


Fig. 19.4. Human female reproductive organs

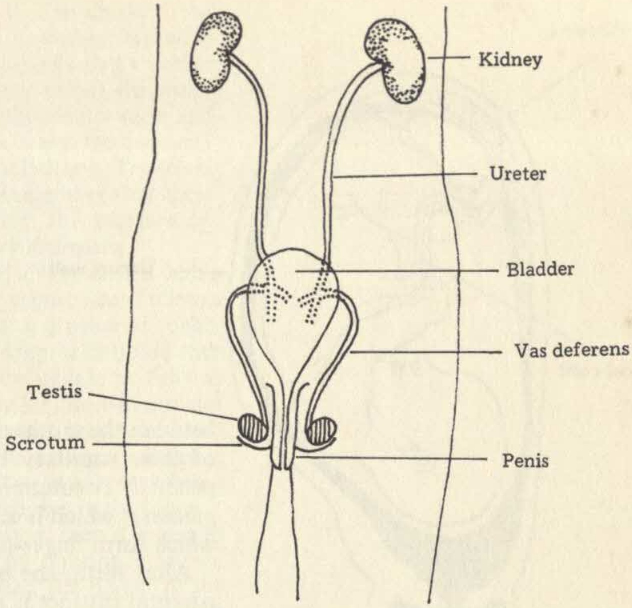


Fig. 19.5. Human male reproductive organs

Reproduction

The female reproductive organs (Fig. 19.4) in mammals consist of two *ovaries* which can be seen as small white oval bodies, in the dorsal wall of the abdomen under the kidneys. They produce the *ova*, or egg-cells, which, when ripe, are set free at intervals into the openings of a pair of *oviducts*, or *Fallopian tubes*, along which they travel to their lower parts, which are much thickened. The two tubes join together to form the *uterus*, or womb, which communicates with the outside opening, the *vulva*, by the *vagina*.

The male reproductive organs (Fig. 19.5) are the paired, oval *testes*, which are formed during development in much the same position as are the ovaries, but which sooner or later move backwards to lie in two *scrotal sacs* (one sac in man) near the surface. The testes produce the *sperms* which are released down the male ducts or *vasa deferentia* through the urethra to the *penis*. The latter is a copulatory organ, by means of which sperms are transferred into the vagina of the female. When this happens the sperms swim up the Fallopian tube to unite with or fertilize one of the ova on its way down the tube. Fertilization thus takes place in the Fallopian tube.

The fertilized ovum or embryo then passes down the tube till it reaches the wider part of the uterus, or womb, where it attaches itself to the wall and begins to grow by active cell-divisions. The length of development of the embryo in the uterus varies with the type of mammal. For example, in man it is usually nine months, in the rabbit three weeks, while it is up to twenty months in the elephant. This period is called the period of *gestation*. The embryo gets a supply of oxygen and food from the blood-stream of the mother, and is able to remove excretory matter in the same way. This exchange of materials

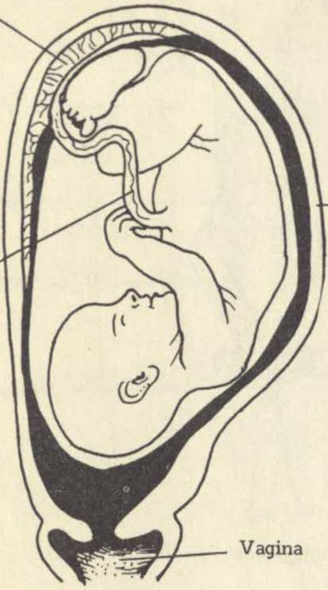


Fig. 19.6. Human embryo in womb

between the mother and the embryo is not achieved through a continuity of their capillary blood-vessels since the embryo has its own independent circulation of blood. The exchange is done through the *placenta*, which is an outgrowth of the embryo itself, and its membranes which form finger-like processes in the uterus wall (Fig. 19.6).

After birth, the baby is helpless and needs much parental care. The parental instinct is most highly developed in the mammals. The young are fed on milk produced by the *mammary glands*. The milk contains all that makes a complete diet, and is easily digested and absorbed. The baby is sheltered and cared for until it is able to look after itself.

It is worth pointing out here that the reproductive and urinary organs are closely associated and are very often referred to collectively as the *uro-genital organs*. Thus the bladder of the urinary organs opens into the female vulva or the male urethra so that, for instance, the urethra convey not only the sperms from the testes, but also the urine from the bladder.

SUGGESTED PRACTICAL WORK

1. (*a*) Your teacher will dissect for demonstration a male and a female mammal. Examine the lungs and the blood supply they receive from the heart. (In what way does the blood carried by the pulmonary artery differ from the blood in all other arteries of the body?)

(*b*) Notice the form and position of the kidneys; follow the renal artery and the renal vein as far as possible within the kidney when the teacher has cut through one to expose the internal parts. Trace out the path of ureters from the kidneys to the bladder.

(*c*) Make a careful study of the reproductive organs of the male and female mammals, and name the following parts: (i) *Male:* Testis, vas deferens, spermetic cord, seminal vesicle, bladder, prostate gland, penis, urethra. (ii) *Female:* Ovary, Fallopian tube, uterus, vagina, vestibule, bladder, urethra.

2. Breathe through a glass tube into some clear lime-water in a test-tube. Does the clear lime-water remain unaltered or does it change its colour? Offer a chemical explanation for the results you observe.

With a bicyle pump blow air from the atmosphere into clear lime-water. What results do you observe? What do these experiments lead you to conclude about the amounts of carbon dioxide in inhaled and exhaled air?

3. Your teacher will set up the model shown in Fig. 19.2 to illustrate the action of the diaphragm during breathing. In the model the bell-jar is used to represent the chest-walls. Across the mouth of the bell-jar is tied a rubber sheet which represents the diaphragm. The glass tube represents the wind-pipe and the rubber balloon, the lung. Try to pull down the rubber sheet and watch what happens to the balloon; does air enter or leave the balloon? Then push up the rubber and notice what happens to the balloon. Try to explain what you see in terms of pressure and volume. (Remember that these vary *inversely*. That is, when the volume *de*creases then the pressure *in*creases, and when the volume *in*creases then the pressure *de*creases.)

4. It is quite an easy matter to discover the amount of air contained within the lungs. Take a large bell-jar or bottle and fill it with water; invert it into a bucket or sink filled with water and introduce one end of a piece of rubber tubing into the open end of the jar or bottle. Take a deep breath and then place the other end of the tube into your mouth. Now exhale as fully as possible into the tube. Your exhaled breath will enter the jar and will displace some of the water. The volume of water displaced should be marked and measured by means of measuring cylinders. The volume of water displaced will be virtually the same as your lung capacity, though it must be remembered that there is always a certain amount of residual air remaining in the lungs.

If the lung capacities of a class of pupils are investigated, then it is best to calibrate the large jar first. This can easily be done by pouring a known volume of water into the inverted jar, and then marking the height of the water on the side of the jar by means of some waterproof material such as shoe-dye. This procedure is then repeated until the jar is fully calibrated.

CHAPTER TWENTY

The Nervous System in Mammals

As indicated in Chapter 1, all living things show *irritability*—that is, they can adapt themselves in response to changes in their surroundings. In higher animals there is a need to respond quickly to external stimuli in order to obtain food, and as the sense-organs are elaborate and the number of muscles is great, a complicated nervous system has been evolved to control the impulses. The nerves consist of the *central nervous system* (that is, the *brain* and the *spinal cord*) and the *nerves*. The nerves carry impulses from the sense-organs to the central nervous system and also from the latter to all parts of the body.

The Brain

The brain (Fig. 20.1) is the enlarged and complex anterior end of the spinal cord, which lies within the neural arches of the vertebrae of the backbone (see Chapter 15). There are various parts of the brain which control various impulses of the body. We all know that we use our brains for thinking, but there are various forms of this activity. Some of them take place spontaneously (*reflex*, or *involuntary*, *action*) and others are *voluntary*—that is, need deliberate effort. We shall discuss these two types of action in greater detail later.

The main parts of the brain are: the *medulla oblongata*, the small brain (*cerebellum*), and the big brain (*cerebrum*). The largest part and perhaps the most important part of the brain is the big brain, or cerebrum. Its surface is rather folded and there is a deep groove at the top which divides it into two halves. The big brain is responsible for the control of all deliberate, voluntary actions which we normally associate with the mind, such as reasoning and memory. There is a relationship between the size and complexity of the cerebrum as regards the size of the mammal, and its level of intelligence. Man has the largest and most complicated cerebrum in proportion to the size of his body, and is the most intelligent of mammals; he depends far less on instinct. Unlike man, the lower vertebrates show little difference between the size of their cerebrum and cerebellum, and their cerebrum is not folded; their behaviour shows less intelligence and is more controlled by instinct.

Fig. 20.1. The human brain

Below the cerebrum is the little brain, or cerebellum, the surface of which also presents a folded appearance. This part of the brain maintains the co-ordination between the various movements in the body. For example, if you have to bend your body in response to an instruction from the cerebrum, the little brain will automatically send out impulses to other parts of the body to enable them to move in ways that will restore a proper balance of the body.

At the lower part of the whole brain—that is, below the cerebellum—and at the position where the brain makes contact with the spinal cord,

there is the spinal bulb, which controls a number of involuntary or reflex activities of the body. Some of these actions are the heart-beat and breathing.

The surface of the brain is grey and called the *grey matter*. This is made up of nerve-cells. Below the surface the brain is white and consists of nerve-fibres. This is called the *white matter*. The number of nerve-cells determines the capacity of the brain for conscious or voluntary action; it is considered an advantage that the grey matter which contains the nerve-cells is on the outside of the brain, where further growth and folding take place more easily.

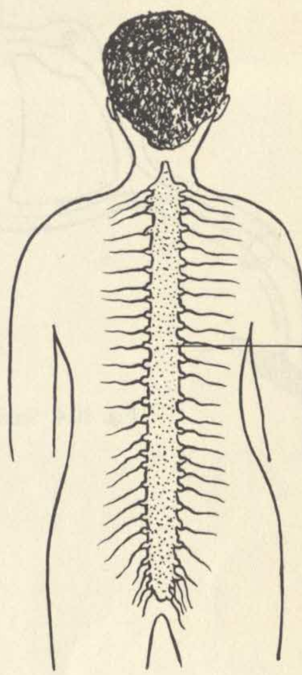


Fig. 20.2. The spinal cord

The Spinal Cord

The spinal cord (Fig. 20.2) runs throughout the length of the body and lies enclosed in the vertebrae of the backbone. It is nearly divided into two halves by two grooves in the vertical plane and has a central canal containing fluid. In cross-section (Fig. 20.3) it is found that, unlike the brain, the grey matter of nerve-cells lies within the white matter of nerve-fibres, and is shaped rather like an H.

A pair of spinal nerves (nerve-fibres) is given off between every two vertebrae, and these spinal nerves serve the limbs and other parts of the body except the head, where the nerves of the eyes, ears, nose, and face run directly to the brain. Each spinal nerve arises from two roots, a dorsal root made up of *sensory fibres* and a ventral root consisting of *motor fibres*. The sensory nerve-fibres carry impulses inwards through the two dorsal horns of the grey matter while the motor fibres carry the impulses outwards via the two ventral horns of the H-shaped grey matter.

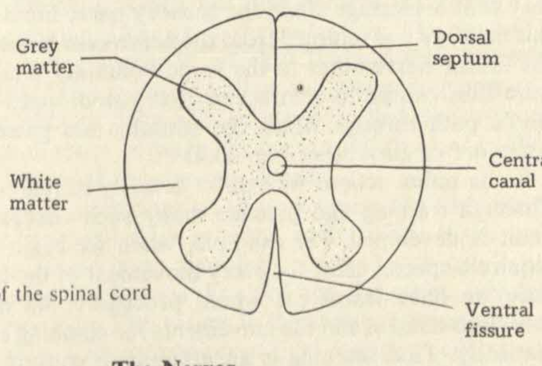


Fig. 20.3. Section of the spinal cord

The Nerves

We are now in a position to consider in detail the function of the nerves, which is to carry impulses. As mentioned above, we have the sensory nerve-fibres which carry impulses from the sense-organs, such as the eye, the ear, and the nose, as well as other sensitive nerve-endings in the skin, to the brain and spinal cord; the motor nerve-fibres carry the impulses outwards from the central nervous system to the muscles. As a result of this we have sensations of sight, hearing, smell, movement, feeling, and the like. But before any such sensation is produced the central nervous system sorts out the impulses sent to it from the sensory nerves, and can then develop two types of reactions: voluntary actions (controlled by will) and reflex actions, or involuntary actions.

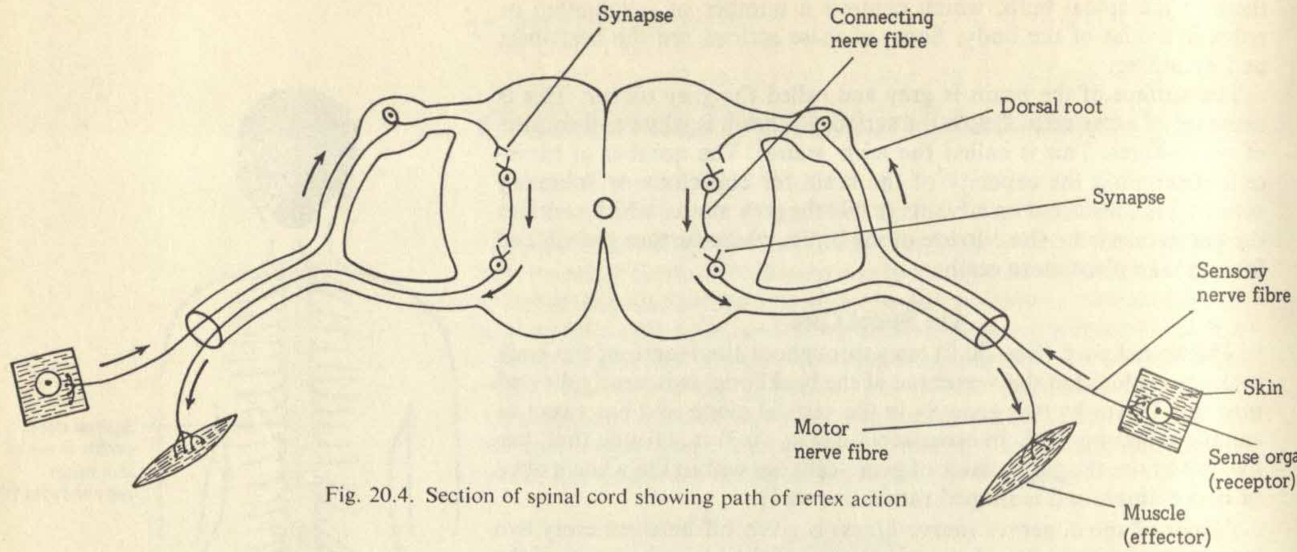


Fig. 20.4. Section of spinal cord showing path of reflex action

Reflex Action

Our simplest response to an external stimulus, such as a protective response, is a reflex action. For example, if by mistake you pick up a hot object, you quickly let go of it without any conscious thought. In the fraction of a second when all this took place, the sensitive nerve-endings in the touch-organs of the skin were stimulated by the pain and they sent a message along the sensory nerve-fibres to the spinal cord; this message was returned from the nerve-cells of the spinal cord through the motor nerve-fibres to the same voluntary muscles. These muscles were thus caused to contract so that you dropped the hot object. The whole path through which the stimulus has passed is known as the *reflex arc* or *curve*. (See Fig. 20.4).

Some reflex actions we exhibit actually started as voluntary actions. Through training and practice many such changes take place and a habit is developed. For example, when we begin to climb a tree we require a special effort for every movement of the body and limbs, but once we have learnt the whole procedure, we do not require any conscious control and the movements for climbing are carried out automatically. Thus learning is an attempt to convert a voluntary action into a reflex one.

Voluntary Action

In a voluntary action the same order is followed as in a reflex action in the transmission of the impulses to the central nervous system and outwards again to the muscles, but here the nerve-impulse takes a much longer path than in a reflex action. Again, as we found in the functions of parts of the brain, the centre of voluntary action is in the fore-brain while that of reflex actions is in the spinal cord, or hind-brain.

Often voluntary action appears to over-ride reflex actions. For example, if by mistake you picked up a very hot plate, your first reaction

under reflex would be to drop it, but when you realize that this would break the plate, you make an effort under voluntary action to bear the heat until you can put the plate down gently. Here the message from the touch-organs in the skin has finally gone from the spinal cord to the fore-brain for action in modifying the reflex action.

The Sense-organs

We often speak of the five senses of sight, hearing, taste, smell, and touch, but we also have a sense of balance. The most highly specialized sense-organs are those of sight and hearing in the form of the eye and the ear. The less complex sense-organs are the olfactory organs for smell, the tongue for taste and the small organs in the skin and muscles.

In the case of smell, the nose forms the wall of the two passages which lead to the actual olfactory organs, whose sense-cells are stimulated by chemical substances. For this stimulation to be possible the surface of the sense-cells must be kept moist by mucus-producing cells. The chemical stimulus received by the olfactory sense-cells is passed along the fibres of the olfactory nerves to a special region in the brain.

In the case of the tongue, the detection of taste is carried out by taste-buds, which are groups of sensory cells at various positions on the surface of the tongue. Taste-buds grouped in front of the tongue detect sweetness and saltiness, those at the back detect bitterness, and those at the sides, sourness.

Structure and Function of the Eye. The eye (Fig. 20.5) consists mainly of the spherical eye-ball which is exposed only in front as the transparent *cornea*, over which the skin, which has also become transparent, is stretched. This skin covering is known as the *conjunctiva*. The eye-ball is attached by muscles to the socket in which it lies and these muscles control its movements. The eye-ball is hollow and the greater part of it is filled with a transparent jelly-like substance called the *vitreous humour*, while the small space between the cornea and the *lens* is filled with a watery fluid known as the *aqueous humour*.

The wall of the eye-ball itself consists of three layers. On the outside is a very tough white tissue called the *sclerotic*, or the 'white of the eye'; in the middle is a pigmented layer plentifully supplied with capillaries called the *choroid*; inside this layer is the third one, the *retina*, which is pigmented on its inner side. The retina is the sensitive layer and receives the light. There is a concentration of light-sensitive cells at one spot which is known as the *yellow spot*. An *optic nerve* arises from the retina at a point known as the *blind spot*, which is not sensitive to light.

The three layers of the eye-ball do not continue on the front of the eye in the same forms. The sclerotic becomes the transparent cornea already mentioned, while in the case of the choroid, the ends hang in front as pigmented curtains, known as the *iris*, which leave a round aperture known as the *pupil*. The part of the retina at the front is taken up by the lens; this is held in place by the *suspensory ligament* which in turn is attached to projections of the choroid called *ciliary processes*.

Now we come to consider the way in which the eye functions as a sense-organ. When light enters the eye and falls on the sense-cells of the retina, impulses are sent by these cells along the optic nerve to the brain,

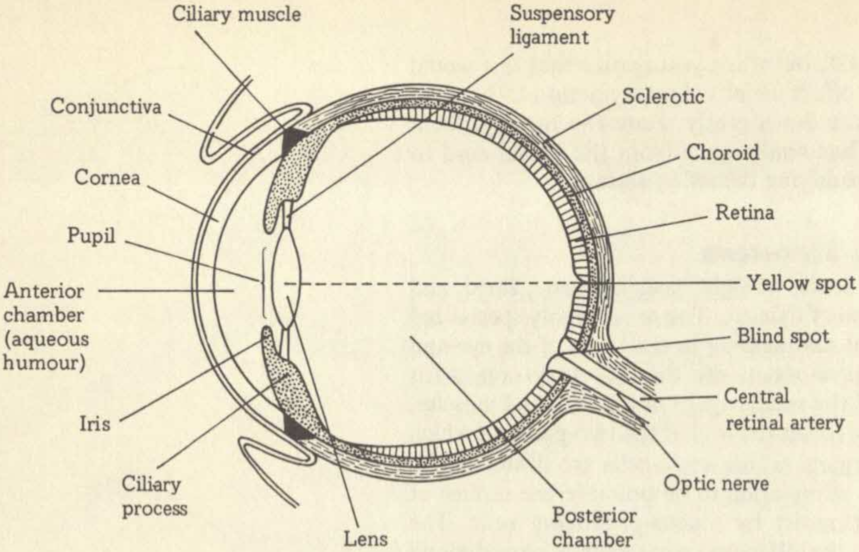


Fig. 20.5. Vertical section of the eye

where they are interpreted as a picture of the outside world. Without light to stimulate the sense-cells of the retina, we cannot see. The image formed on the retina is inverted, but this is corrected by the brain. The structure of the eye is well adapted for obtaining a sharp picture of the object that is being looked at. Thus the cornea, the lens, and the other transparent parts, such as the two types of humour filling the hollow eye-ball, help to transmit light.

To achieve this successfully it is essential that the rays of light which penetrate the eye be restricted. This is done by the pigmented parts such as the iris, the choroid layer, and the back of the retina. The sharpness of the image is achieved with the aid of the cornea, aqueous humour, the lens, and the vitreous humour.

The mammalian eye can be compared with the photographic box-camera. Both consist of a hollow chamber with an opening in front carrying a lens to refract light. The light forms an image on a sensitive surface, which is the retina in the case of the eye, and the plate or film in the camera. In both cases the inside of the chamber is lined in black to prevent blurring and reflection, and the aperture can be altered to control the amount of light which enters. The iris of the eye is equivalent to the 'stop' of a camera in restricting the entry of light. One essential difference is in altering the focus for objects at different distances. In the camera the lens is moved forwards or backwards to achieve this, while in the mammalian eye it is the shape of the lens and hence its focal length that is altered. This behaviour of the lens is called *accommodation*, and is carried out by the ciliary muscles which hold the lens.

Short- and Long-sightedness. By *short-sightedness* we mean the condition certain people have in which they can only clearly see objects that are near to them; beyond a certain distance they cannot see any object. The explanation of this is that the cornea which directs the light through the lens is so curved that the increased converging effect brings the parallel rays of light from a distant object to a focus before reaching the retina (Fig. 20.6).

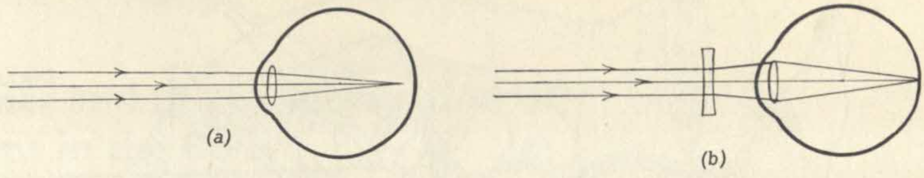


Fig. 20.6. (*a*) Light rays in short-sightedness; (*b*) correction of short-sightedness

To correct this, short-sighted people should wear spectacles with suitable concave lenses which scatter the rays of light a little more before entering the eye, so that the image falls on the retina (Fig. 20.6).

By *long-sightedness* we mean the condition in which people can see distant objects clearly but not nearby objects. This is explained by the

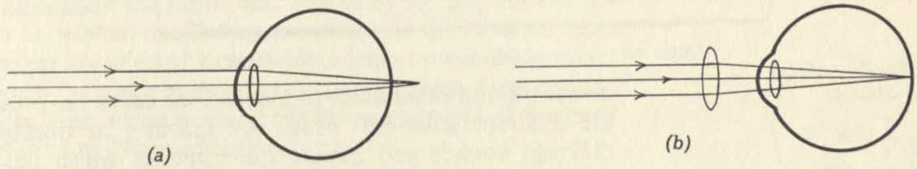


Fig. 20.7. (*a*) Light rays in long-sightedness; (*b*) correction of long-sightedness

fact that the cornea is insufficiently curved and, as a result, the rays of light from near objects come to a focus behind the retina (Fig. 20.7).

To correct this, the long-sighted person has to wear glasses with suitable convex lenses which help to converge the rays to some extent before entering the eye, so that the image is brought nearer, and is formed on the retina (Fig. 20.7).

Structure and Functions of the Mammalian Ear. The ear (Fig. 20.8) is a sense-organ of hearing and position. In the mammal it consists of three parts; the *external*, or *outer*, *ear*, the *middle ear*, and the *inner ear*. Only mammals have the external ear, which is largely the part seen on the outside of the head and to which we often refer simply as the 'ear'. This is called the *pinna*. It may be used in direction-finding, and it collects the sound-waves and directs them through a short tube, the *meatus*, to the ear-drum, or *tympanic membrane*. This membrane vibrates and transmits the sound-waves to the three bones of the middle ear.

The *middle ear* is a chamber filled with air and connected with the pharynx by means of the *Eustachian tube*, which is a duct that enables pressure to be kept equal on the two sides of the ear-drum. Three connected bones, or *ossicles*, are found across the chamber of the middle ear. These are each specially shaped, and beginning from the ear-drum they are named the hammer, or *malleus*; the anvil, or *incus*; and the stirrup, or *stapes*. These bones transmit and amplify the sound waves from the ear-drum to a tiny membrane, the *fenestra ovalis*, or oval window, on the other side of which is the inner ear.

The *inner ear* lies within the bones of the skull and consists of a complicated arrangement of tubes surrounded by fluid, the *perilymph*. The sound-waves from the round window are transmitted through the

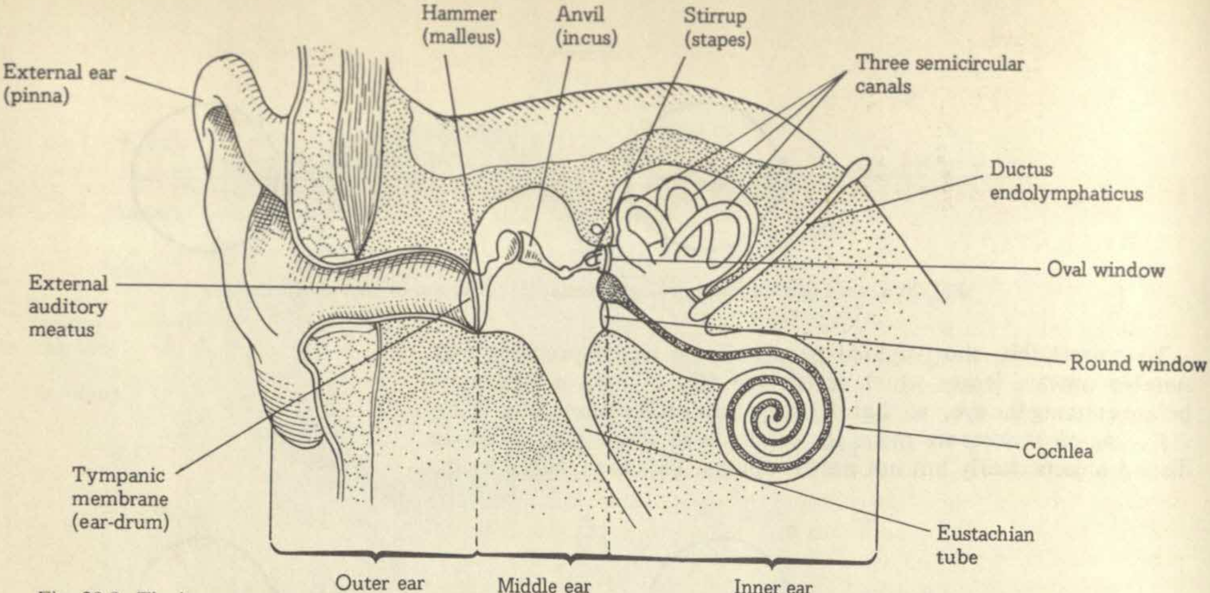


Fig. 20.8. The human ear

perilymph and other fluids to a coiled sac called the *cochlea.* In this sac are different sense-cells which are sensitive to vibrations caused by different sounds and initiate the impulses which pass through the *auditory nerve* to the brain. In this way hearing is effected.

The other part of the inner ear is concerned with balance, and consists of three specially arranged *semi-circular canals.* Each of them contains a fluid, *endolymph,* into which project minute hairs. Highly sensitive nerve-endings are present in the bases of the hairs. As the head moves the endolymph drags on the hairs stimulating the nerves. This mechanism gives us our sense of balance.

SUGGESTED PRACTICAL WORK

1. Study a few reflex actions such as the following:

(*a*) *Cerebral reflex.* Look into the eye of a friend and notice the position of the pupil. Let him look towards a strong light; you will notice that the pupil begins to narrow. Then let him turn away from the light; the pupil opens wider. Similar effects can be obtained by looking at a distant object or a near object.

(*b*) *Spinal reflex.* The knee-jerk reflex is easily demonstrated. Let your friend sit in a chair and place one knee over the other. Use the edge of a book to strike the hanging leg just below the knee-cap; it will kick forward spontaneously.

•**2.** (*a*) Obtain the eye of a large mammal such as the sheep or cow from a butcher. Note the optic nerve, the layer of fat which 'cushions' the eye within the socket, the muscles attached to the eye-ball, and the transparent cornea.

Using a pair of sharp scissors, cut the eye so as to obtain a front half and a back half. Is it easy or difficult to cut through the outer layer of the eye—the sclerotic? Look inside the back half of the eye and try to locate the blind spot; is the retina firmly fixed to the rest of the eye, or not? Next examine the inside of the front half of the eye, and try to identify the lens, the iris, and the ciliary muscles. Carefully dissect out the lens and look for the pupil.

(*b*) If your school has models of the eye and the ear, examine them in order to understand their structures properly.

3. Your teacher will set up demonstrations to illustrate the cause of long- and short-sightedness and how lenses are used to correct them.

CHAPTER TWENTY-ONE

Hormones and the Co-ordination of Functions in the Body

So far we have considered the structure and functions of various parts of the mammalian body separately, and this may have given the impression that the various parts work independently of each other. This is quite a wrong impression, for the various parts of the body are dependent on each other for the harmonious working of the whole. Every part of the body functions only when it is stimulated as a result of impulses received from the central nervous system. The latter also controls the activities of the limbs and organs by sorting out the impulses in order to prevent conflicting situations. In this process more important impulses are allowed to take precedence over less important ones. The process by which the central nervous system sorts out the impulses, for the harmonious working of the various parts of the body as a unit, is referred to as *co-ordination*.

In exercising this function in the body, the central nervous system is aided by *hormones*. Hormones are secretions of certain glands in the body which, unlike glands such as the liver and gall-bladder, have no ducts. They are referred to as *ductless*, or *endocrine*, *glands*. The hormones are passed directly into the blood-stream and distributed to all parts of the body; they are sometimes called chemical messengers. It must be emphasized that the working of the ductless glands is itself under the control of the central nervous system.

The hormones have remarkable effects on the body in controlling growth, development, and metabolism. The main ductless glands in the mammal are (Fig. 21.1):

(*a*) The *thyroid*, found on each side of the larynx.
(*b*) The *pancreas*, near the alimentary canal.
(*c*) The *adrenals*, found over the kidneys.
(*d*) The *pituitary*, found below the brain.
(*e*) The *testes* and *ovaries*, the reproductive organs.

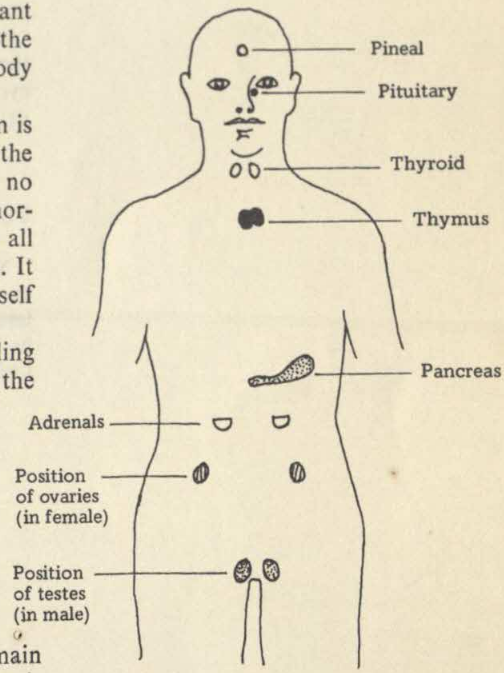


Fig. 21.1. The main ductless glands of the body

The *thyroid* secretes *thyroxin*, which contains iodine and whose main effect is to speed up all metabolism in the body. When the secretion is reduced—for example when iodine is lacking in the water we drink, not only is metabolism slowed down, but the gland itself may become swollen. This is because it tries to make enough of the hormone with very little iodine. The swollen condition of the gland is called *goitre*. Iodine deficiency can also result in excess fat. In children lack of the hormone results in suppressed growth both physically and mentally; such children look like dwarfs and are called *cretins*. When too much of the hormone is secreted it speeds up metabolism and can produce a restless, anxious, and confused mental state.

The *pancreas* secretes a hormone that is perhaps the most familiar. This is called *insulin*; it controls the use of sugar and aids the liver and muscles in converting sugars into glycogen. When this secretion is insufficient the oxidation of sugars or their conversion into glycogen is reduced and the disease *diabetes* results.

The *adrenal glands* secrete the hormone called *adrenalin* into the blood when we are angry or frightened. Adrenalin raises the sugar content of the blood and causes the heart to beat more quickly. It thus prepares the body for action, and has been called the 'emergency hormone'. Its action is in some respects a reversal of that of insulin and can also produce shivering.

The *pituitary gland* secretes as many as six or more hormones which seem to control the secretions of other ductless glands. Their effect is on metabolism, growth, and the onset of maturity. If any of the hormones is not produced in the right quantities, its effect on growth produces either a giant or a dwarf.

The *testes* and *ovaries*, which are the male and female reproductive organs, secrete hormones which control the development of characters peculiar to the sex. Thus male hormones control the development of the beard and the deep voice in men, while female hormones control the cycle of egg-liberation and changes associated with pregnancy and delivery.

SUGGESTED PRACTICAL WORK

Your teacher will dissect a mammal for demonstration. Of the five principal ductless glands we have already examined the pancreas, the ovaries, and testes. Look for the thyroid and adrenal bodies in this dissection. You will not be able to find the pituitary gland because it is situated beneath the brain, inside the skull and above the roof of the mouth.

PART TWO

CHAPTER TWENTY-TWO

Microscopic Plants

As mentioned in Chapter 2, plants as well as animals exist in forms that illustrate evolution, and it is therefore instructive to begin the study of plants with the acellular and other microscopic forms.

Chlamydomonas

Structure. (Fig. 22.1.) This is an acellular plant like *Amoeba* or the semi-plant *Euglena* described in Chapter 3. It belongs to the group of plant forms known as the *algae* which commonly colour the water in aquaria green.

Chlamydomonas is a free-living plant that swims about actively in ponds and ditches by means of its two long *flagella* at the front of the cell-body. It is usually spherical or oval in shape and has a cellulose cell-wall. Below the flagella are two *contractile vacuoles*, and next to these is an orange-coloured pigment spot called an *eyespot*. Under the microscope it will be found that the protoplasm of the main part of the body has a single large *chloroplast*, roughly cup-shaped, which contains chlorophyll. Inside the posterior end of the chloroplast is a bright, rounded body known as the *pyrenoid*, and in the cavity of the chloroplast lies the *nucleus*.

Nutrition. Since it is a plant, the mode of nutrition in *Chlamydomonas*

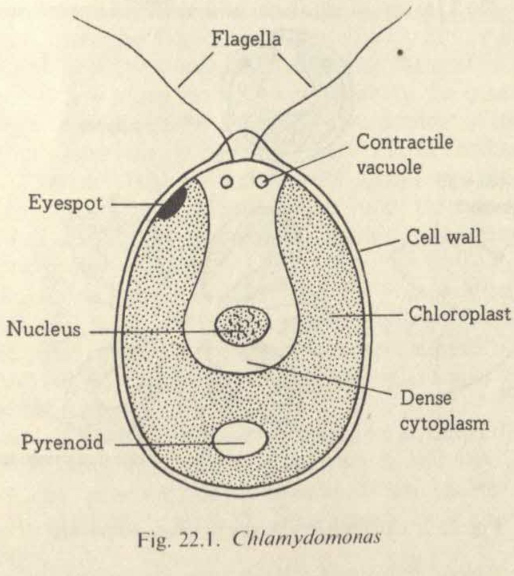


Fig. 22.1. *Chlamydomonas*

is holophytic, that is, by means of photosynthesis. *Chlamydomonas* absorbs the necessary salts, carbon dioxide, and water over its entire surface from the surrounding water, and during the making of starch in

sunlight, oxygen is produced and given off. In the same way, respiration involves the whole surface of the cell-body.

Life-history. *Chlamydomonas* has a life-history that involves either asexual reproduction by means of *zoospores* within the parent body, or sexual reproduction involving a union of the contents of two individuals (conjugation) to form a *zygospore*. The formation of zoospores within the parent body, which takes place under less favourable conditions, proceeds by division of the contents two or three times, after which the cell-wall of the parent body breaks down and the new individuals (zoospores) are released. The zoospores begin to swim about and live like the parent. Sometimes the young zoospores fail to develop flagella while still in the body of the parent, but repeated divisions continue and the numerous individuals produced are embedded in mucilage. This stage of development is known as the *palmella stage*.

Sexual reprodution takes place under favourable conditions. The contents of the cell-body divide repeatedly to form individuals, as in the formation of zoospores. When these escape they unite in pairs (conjugation) by their anterior ends (Fig. 22.2), and are known as *gametes*. The new cell which is formed in each case is called a *zygote*. The

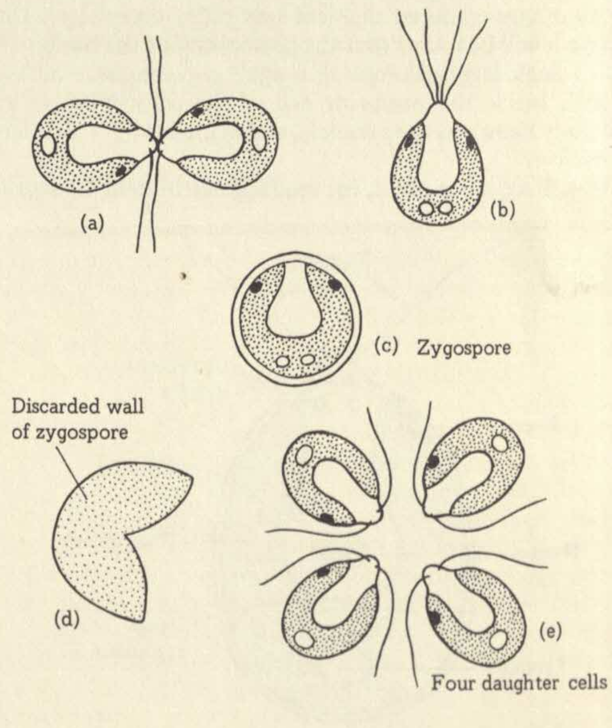


Fig. 22.2. Conjugation stages in *Chlamydomonas*

zygote remains dormant during a dry period with the aid of a thick wall, which it secretes. It is then referred to as the zygospore, and during this period new individuals are formed by cell-divisions of its contents.

When conditions improve, the thick wall breaks down and the new individuals are released.

Chlamydomonas thus gives us an example of the very beginnings of sexual reproduction, as we also found in *Paramecium* in Chapter 4.

Spirogyra

Structure. *Spirogyra* is also an alga but unlike *Chlamydomonas* it is multicellular. It is a green filamentous plant (Fig. 22.3) commonly found

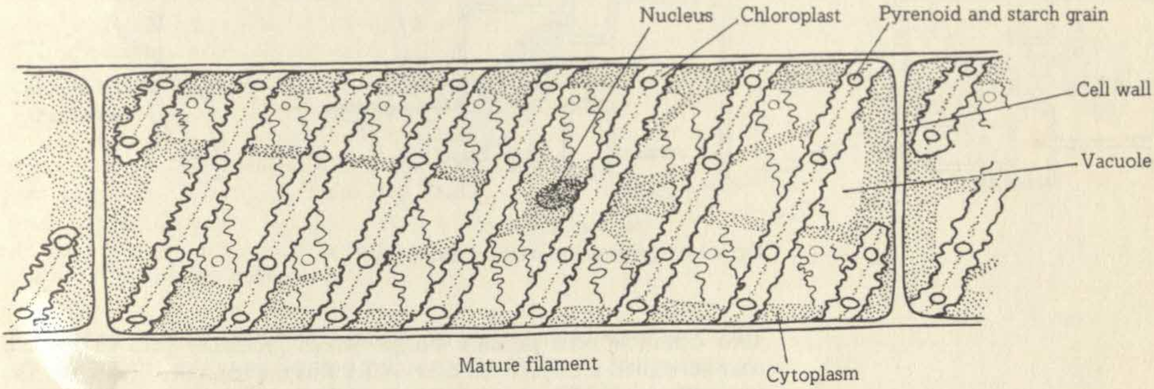


Fig. 22.3. *Spirogyra* (a single cell of a mature filament viewed under the microscope)

floating or otherwise near the surface in most fresh-water ponds, streams, or rivers. The filament consists of a chain of cylindrical cells, each enclosed in a thick cellulose wall. The filament is covered by a mucilaginous layer which makes it very slimy to the touch.

Spirogyra is remarkable for the spiral arrangement of its long chloroplasts, which have distributed on them bright bodies known as pyrenoids. There is a large central vacuole containing sap, in the middle of which the nucleus is suspended by slender threads of cytoplasm. *Spirogyra* has no flagella or eyespots, and therefore cannot move by itself as *Chlamydomonas* does.

Nutrition. *Spirogyra* obtains its food by photosynthesis, as do all green plants. If it is exposed to light starch grains are formed, especially around the pyrenoids, and the starch can be detected by staining the filament with iodine. Gaseous exchange takes place over the entire surface of the filament.

Life-history. *Spirogyra* increases in length by repeated divisions of the cells and their elongation, the plant growing in this way into a tangled mass. As growth proceeds the filament splits into shorter lengths, each of which also proceeds to grow. This *fragmentation* is a form of asexual reproduction.

The more interesting aspect of the life-history of *Spirogyra* is its mode of sexual reproduction (Fig. 22.4), which begins when the rainy period is coming to an end. The process is called *conjugation* and takes place between the cells of two filaments which happen to lie side by side.

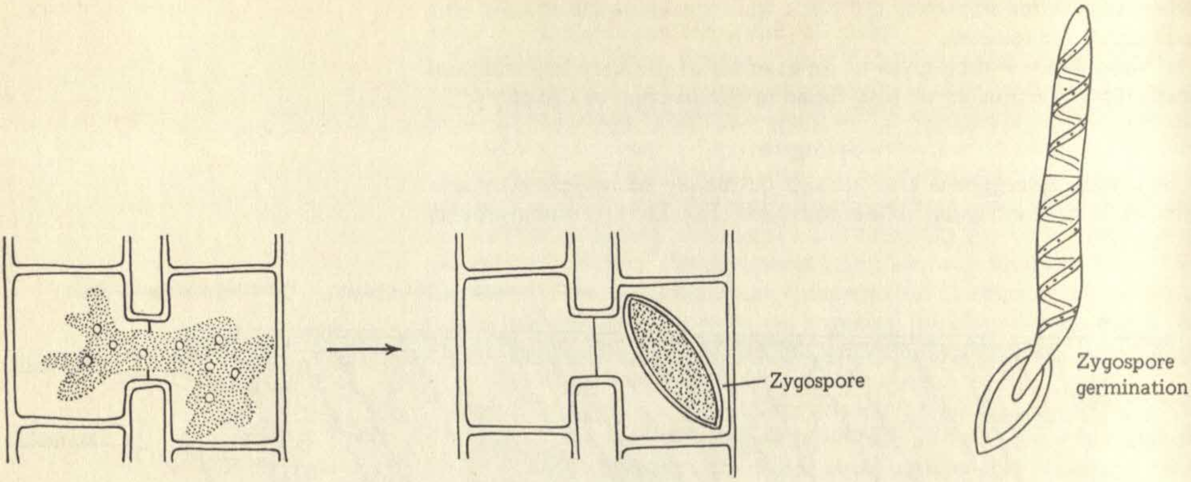


Fig. 22.4. Conjugation stages in *Spirogyra*

Two opposite cells produce bulges which gradually join to form a channel called a *conjugation tube*. After this the contents of each of the two cells are withdrawn from the cell-wall and form into a structure called the *gamete*. The gamete from one cell then passes through the conjugation tube into the opposite cell, where the two gametes fuse. It is often found that where conjugation takes place between many opposite cells of two filaments, the contents of the cells of one filament pass into the cells of the other filament. Hence the filament which sends out its gametes is regarded as a male filament while the other which receives the gametes is regarded as a female filament.

The single cell formed by the union of the two gametes is a zygote, and it soon secretes a thick wall around itself and becomes a zygospore. Later the old cell-walls of the two filaments rot away and the zygospore sinks to the bottom of the water. At this stage the filaments appear yellowish. The zygospore is able to rest unharmed during the dry period, but when the rains begin again, the thick wall bursts, and a young filament grows out.

Rhizopus: The Common Mould

Rhizopus is a microscopic plant belonging to another group known as the *Fungi*. These are plants because they have branched bodies and have methods of reproduction that are commonly found in plants. But their mode of feeding is not like that of green plants for they do not contain chlorophyll and thus do not manufacture their own food by photosynthesis. Their method of feeding will be described later.

Not uncommonly when bread, over-ripe fruits, leather, or cooked foods are left for some time in a damp place, they become covered with mould, which consists of the bodies of certain fungi. *Rhizopus* and *Mucor* are white, the blue-green patches may consist of *Penicillium*, while the yellowish-green portions may well be *Aspergillus*.

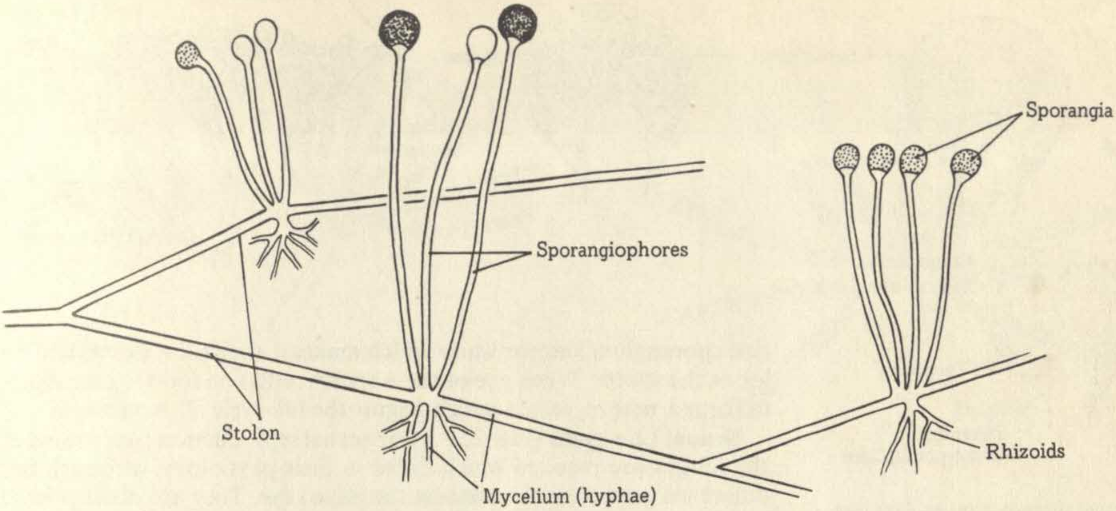


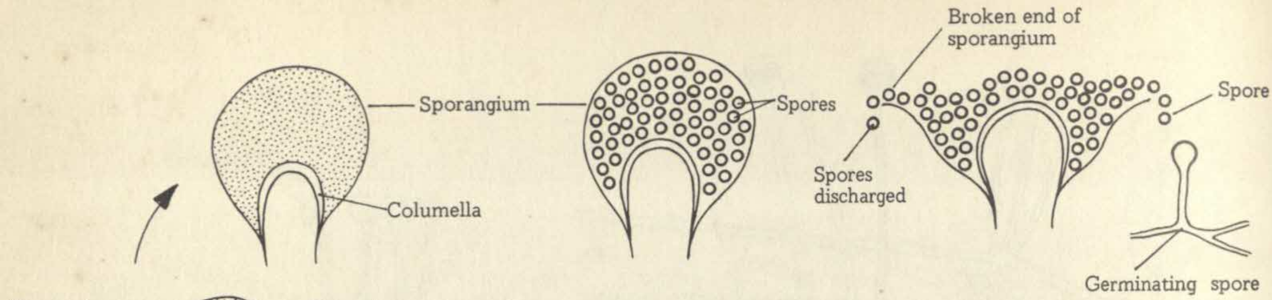
Fig. 22.5. *Rhizopus stolonifer*

Structure. *Rhizopus stolonifer* (formerly known as *R. nigricans*) (Fig. 22.5) is a very common species in the tropics. Its body, the *mycelium*, consists of threads called *hyphae*. A hypha is a branched tube lined with cytoplasm in which numerous nuclei are embedded. Some of these hyphae are specialized into arched aerial threads called *stolons* by means of which growth in *Rhizopus* is achieved. At intervals the stolons form tufts of brown branches which penetrate the substratum; from these arise vertical clumps of one or more erect hyphae. This is in contrast to growth in *Mucor* (a temperate species) in which the erect hyphae are isolated. The erect hyphae are not branched and bear structures (*sporangia*) for reproduction, as will be described later.

Nutrition. *Rhizopus*, like most fungi, feeds *saprophytically* on ready-made substances, by absorbing these substances in solution through the general surface of the body or mycelium. The mycelium may secrete enzymes which break down the food substances into materials which can be absorbed.

When it grows on the surface of such food as over-ripe fruit and absorbs glucose in solution, it is able to perform normal (*aerobic*) respiration with the aid of oxygen from the air, and to release carbon dioxide, water, and free energy. In the deeper layers of the fruit, the hyphae of the rhizoids may respire without air (*anaerobic*), and in this case they release carbon dioxide and alcohol. We then say that the juice in the fruit is fermented.

Asexual Life-cycle. (Fig. 22.6.) The commonest method of reproduction in *Rhizopus*, and in most fungi, is the production of great numbers of single cells, called *spores*, which are small enough to be scattered by the wind. The spores are produced at the tips of the erect hyphae in round bodies called *sporangia*, which are cut off from the erect hyphae by cross-walls. The cross-wall bulges into the sporangium forming a *columella*. The sporangia blacken as they ripen. When the air is damp the



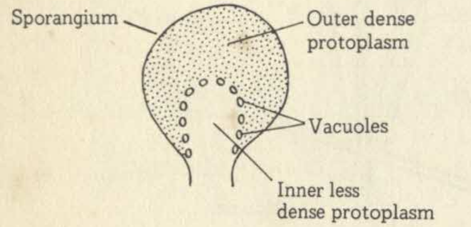
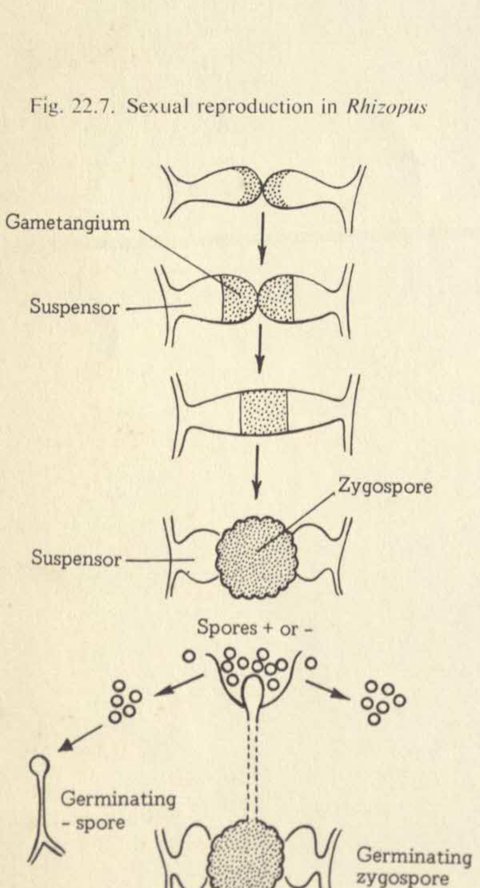


Fig. 22.6. Asexual reproduction in *Rhizopus*

Fig. 22.7. Sexual reproduction in *Rhizopus*



ripe sporangium absorbs water which makes it swell till it bursts and releases the spores. When one of these spores settles on food it germinates to form a new mycelium which begins the life-cycle all over again.

Sexual Life-cycle. (Fig. 22.7.) For sexual reproduction two strains of the fungus are required which differ in their physiology, although this difference cannot be observed by the naked eye. They are distinguished as *plus* and *minus* strains. When hyphae of two such strains come together, they proceed to fuse together at their tips by a process called conjugation. The tips first fill with a dense collection of protoplasm to form gametes and a transverse wall is then formed to cut this off. The part of the hypha left attached to it is called the *suspensor*. Eventually a pore develops between the two tips whose protoplasm (the gametes) intermingle or fertilize each other to form a zygote. The zygote forms a thick black wall around itself and is then known as a zygospore. In this form the fungus can remain dormant for months or even years. Under favourable conditions the zygospore germinates into a single erect hypha bearing at its tip a sporangium which later bursts to liberate spores. These grow into new mycelia, just like those formed by asexual reproduction.

Penicillium and Aspergillus

As mentioned above, the mould which grows on food may also contain the blue-green *Penicillium* (Fig. 22.8) and the yellow-green *Aspergillus* (Fig. 22.9). These two fungi are very closely related, but they differ from *Rhizopus* in having cross-walls in the hyphae of the mycelia. The story of how penicillin, obtained from *Penicillium notatum*, was discovered is well known. As this fungus feeds and grows, there diffuses out of its hyphae into the material on which it grows a substance that is poisonous to many bacteria and other organisms but harmless to the mould itself. Such a substance is called an *antibiotic* and in this case it is known to us as penicillin. When we are ill and penicillin is injected into our bodies, the concentration used is high enough to kill the bacteria which are causing the illness, but sufficiently low to be harmless to the cells of our body. Many other antibiotics, such as streptomycin, are isolated from other fungi, and are of great value in medicine.

As Fig. 22.9 shows, the structures of *Aspergillus* and *Penicillium* are different from that of *Rhizopus*. The sexual life-cycle of *Aspergillus* has only recently been fully studied, and most species of *Penicillium* do not reproduce sexually.

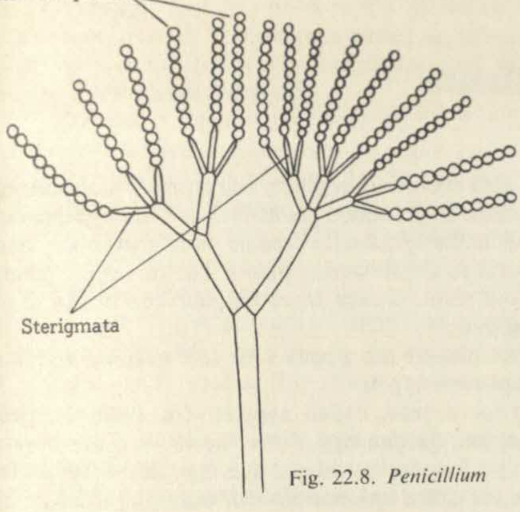


Fig. 22.8. *Penicillium*

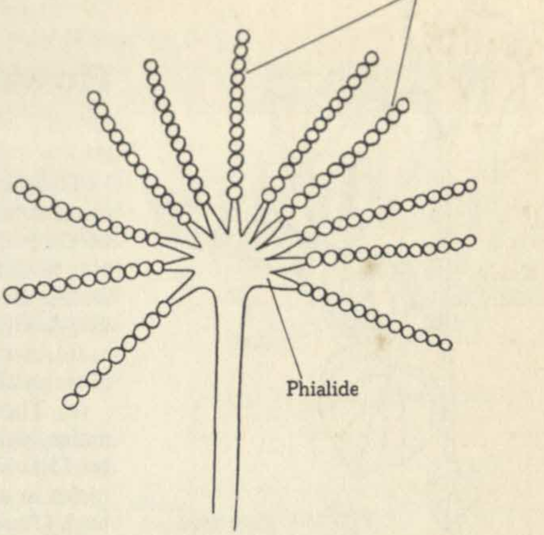


Fig. 22.9. *Aspergillus*

SUGGESTED PRACTICAL WORK

1. Try to obtain *Chlamydomonas* and floating *Spirogyra* from fresh-water ponds and ditches. Your teacher will place a drop of the material on a slide and allow you to examine it under the microscope. See if you can find the flagella of *Chlamydomonas,* and note how actively the plant moves. Examine the internal structure.

The teacher will also mount some of the *Spirogyra,* including the reproductive (conjugation) stages. Make clear drawings of the vegetative and reproductive stages.

2. Moisten slices of bread, orange-peel, or old leather in Petri dishes, cover them with a bell-jar and leave for a few days. As the material becomes mouldy, use a hand-lens to examine the composition of the 'moulds', which may consist of *Rhizopus, Penicillium,* and *Aspergillus.* Mount some in cotton-blue stain and examine under the microscope. Note the mycelium, the sporangiophores, the columella, and the arrangement of the spores.

3. Prepared slides of the reproductive stages of *Mucor* can be examined if the material of *Rhizopus* does not contain suitable stages.

4. Cut a complete coconut fruit in half and allow the 'milk' to drain off. Expose the cut halves to the atmosphere for about thirty minutes and then cover each part with a bell-jar. Examine the white food reserve of the coconut seed every day and note the colour and extent of any 'moulds'; investigate the structure of any fungal growths by means of a microscope. Identify the fungi present, if possible, and try to discover the nature of the food store contained in the white part (endosperm) of the coconut seed (see sections dealing with food tests in Chapter 15).

5. Arrange to visit a cocoa farm, if possible during September or October; make a thorough search amongst the developing crop for signs of 'black pod' disease. This is a fungus disease (*Phytophthora sp.*) which affects the cocoa pods, producing characteristic black or brown patches on the fruits.

CHAPTER TWENTY-THREE

Flowering Plants

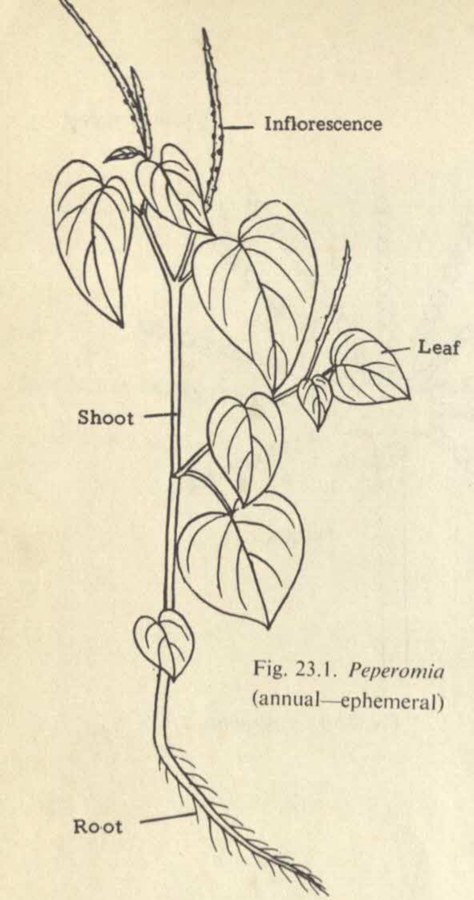


Fig. 23.1. *Peperomia* (annual—ephemeral)

IN Chapter 2 we discussed evolution in plants and animals and pointed out that beginning from the single-celled plants such as *Chlamydomonas*, we encounter other plants that gradually become more and more complex until finally we come to the flowering plants. The flowering plants are the most conspicuous plants we see around us, and can be classified into *herbs*, *shrubs*, and *trees*.

Herbs (or herbaceous plants) are plants with soft tissues, and are often small. They are of *three* types.

(*a*) Those that live for a year, called *annuals*—for example, rice, maize, yam, canavalia, and garden egg. Some, however, have a very brief life-history of only a few weeks and can thus complete several life-cycles in a year; these are called *ephemerals*—for example, the shining bush (*Peperomia*) (Fig. 23.1).

(*b*) *Biennials* are herbaceous plants that live for two years. These are typical of the temperate regions. In the tropics one of the few examples is the flowering onion (Fig. 23.2) which spends the first year in forming the bulb, and the following year produces flowers, then seeds, and afterwards dies.

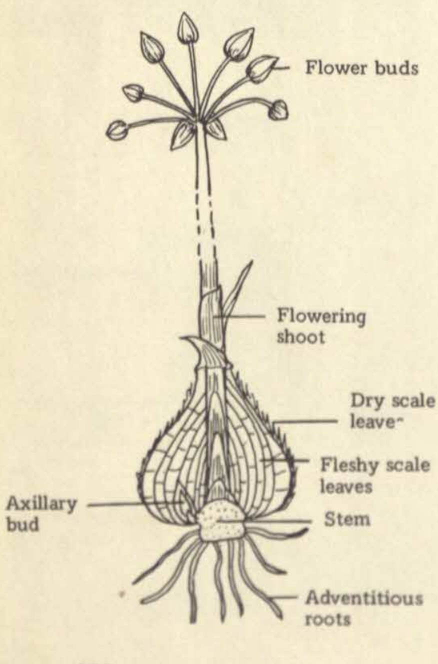
(*c*) *Perennials* are herbaceous plants that live for many years—for example, the ginger (Fig. 23.3), the Canna lily, *Crotalaria*, and other plants which often have storage-organs (see Chapter 24).

Shrubs. These are woody plants with several stems close to the ground. Shrubs and trees have hard, woody tissues. Examples are the decorative plants like the hibiscus.

Trees. These are plants with a single woody trunk of a large size which usually branches high up or sometimes remains unbranched. Examples are the mango, *Delonix* (or the flamboyant), the coconut, and the oil-palm.

Here it should be added that while annuals and biennials are all herbaceous, perennials may be either herbs, shrubs, or trees. Plants are also adapted in many ways to suit the conditions under which they live (see Chapter 3).

Fig. 23.2. Flowering onion (biennial)



External Morphology of a Herbaceous Plant—The Common Vernonia

It is useful to learn the parts of a flowering plant by studying a small tropical herbaceous annual like the common vernonia (scientific name *Vernonia cinerea*), also known as the blue fleabane in some tropical countries (Fig. 23.4). If we dig up this common weed and gently wash off the soil from the roots, we can study its parts. All the roots form the *root system*, while the rest of the plant forms the *shoot system*. The root system is made up of the large *main root* (called the primary, or tap, root) which grows almost straight downwards, and the smaller *branch roots*, which grow outwards and downwards. Above the root

system we come to the shoot system with, first, the *main stem*. This grows upright and has on it *nodes* at which leaves are borne. The bare stem between two nodes is called an *internode*. At the base of the stem are a number of marks, called *leaf-scars*, which indicate positions where leaves have fallen off.

In *Vernonia* a single leaf is borne on a leaf stalk at the node. The base of the leaf (or leaf stalk) makes an acute angle with the stem and this angle is called the *axil* of a leaf. In the axil of each leaf is a bud, called the *axillary bud*. The main stem also bears side branches (or *axillary branches*) which are developed from axillary buds, and *floral branches*, which bear the purple to reddish-purple *flowers*, clustered together into heads called *inflorescences*. At the very top of the main stem—and at the tips of the branches—are *terminal buds* which may also develop into *floral* branches. When the flowers on *Vernonia* are old they become dry and *fruits* are formed as tiny structures bearing hairs. Each fruit contains a *seed*.

The stem, leaves, and root make up the *vegetative part* of the plant, while the flowers and fruit make up the *reproductive part*. We shall now consider the functions of the parts of the plant.

The functions of the *root* are:

(1) To absorb water and dissolved chemical substances from the soil, and to conduct these to the shoot.

(2) To hold the plant firmly in the soil.

(3) To conduct food made in the shoot downwards to the roots.

(4) To store reserve supplies of food in some plants, as in the cassava, manioc, or carrot.

(5) To serve as breathing roots in some plants, as in the mangrove.

The functions of the *stem* are:

(1) To support the branches and the leaves, and hold each of the latter in such a position as to receive as much sunlight as possible.

(2) To support the flowers in the best position for pollination and the fruits in the best position for dispersal of the seeds.

(3) To conduct water and salts from the roots to the leaves and manufactured food material from the leaves to the other parts of the plants.

(4) To store reserve water or food in some plants, like the ginger rhizome or the potato tuber.

The functions of the *leaf* are:

(1) To manufacture the plant's food from the carbon dioxide of the air and the water from the soil in the presence of chlorophyll and sunlight (photosynthesis).

(2) To store reserve food substances in some plants, like the onion and *Bryophyllum*.

The function of the *flower* is to produce fruits and seeds.

The functions of the *fruit* are:

(1) To protect the seeds.

(2) To assist in the scattering of the seeds when ripe.

These functions will be considered in detail later.

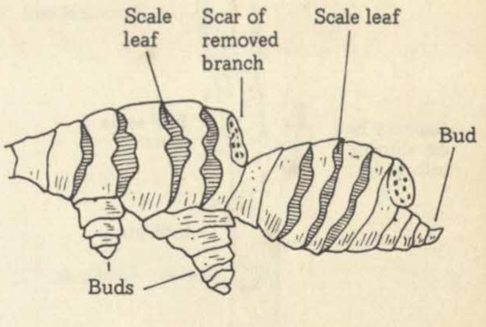


Fig. 23.3. Ginger (perennial)

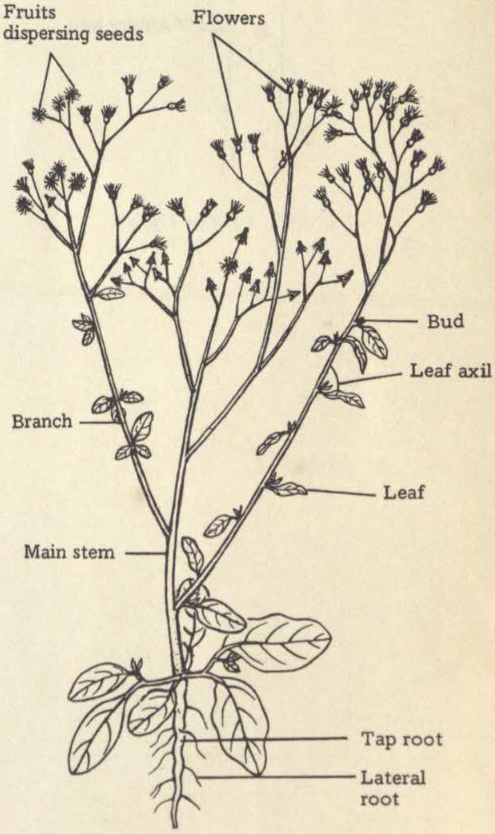


Fig. 23.4. *Vernonia cinerea*

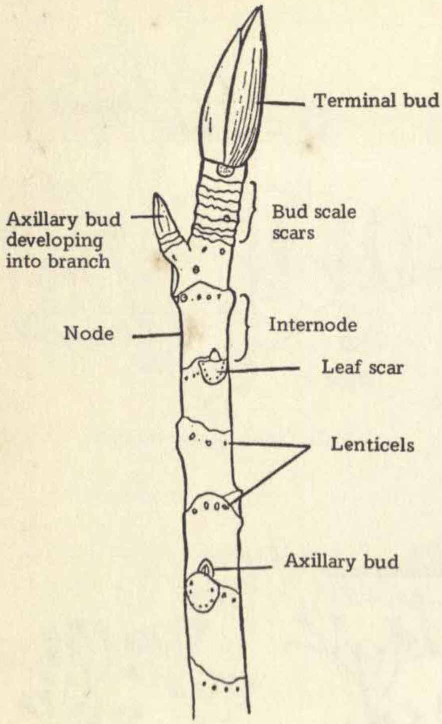


Fig. 23.5. Twig of *Ficus*

Parts of the Twig of a Woody Perennial Tree

Growth in a woody perennial tree (or shrub) appears to continue throughout its life, but the growth is rapid at a certain period or periods of the year, and virtually ceases at other times.

We can recognize the periods of growth by examining a twig. For example, the twig of a *Ficus* species (Fig. 23.5) will show at intervals narrow bands of many rings. These are scars left by bud-scales which protect the buds during the dormant period and are called *girdle scars* or *bud-scale scars*. In most species of *Ficus* there are not less than two such periods in a year. Like the parts of the herbaceous plant described above, there are *leaf-scars*, a *terminal bud*, *axillary buds*, and *axillary branches* which develop from axillary buds. One other special feature of a twig is the presence of tiny brown dots called *lenticels*. These are passages through which air enters the stem, which form when the stomata have been cut off by a layer of cork underneath.

Natural Histories of some Tropical Trees

The life-cycle of a flowering plant begins as the seed, which on germination, gives rise to the seedling plant. The seedling gradually grows into a big plant with branches and leaves. Later, flowers appear and when the ovules are fertilized, fruits begin to develop and enlarge. When the fruits are ripe, they are scattered and, under suitable conditions, the seeds in the fruits germinate into seedlings. So the life-cycle begins again.

This simple account is not as straightforward as it seems when we come to consider actual cases. For example trees (and shrubs) vary in their morphology, leaf-fall, flowering and fruiting periods, and in the relationships of these environmental factors. Before we come to study a few trees, let us examine some of the general features of these periodic events like leaf-fall, flowering and fruiting periods (or cycles) and the role of the environment in these events.

Leaf-fall. We find a number of differences in the leaf-fall of different trees. In *Ceiba pentandra* for example the old leaves are shed just before flowering takes place, and new leaves are formed by the end of the flowering period. But in *Bombax* when the leaves are shed, the tree remains bare for about a month before the flowers appear, and then the new leaves are formed.

Some trees such as *Adansonia*, *Bombax*, and *Antiaria* lose all their leaves but others such as *Fagara*, *Kigelia* and *Balanites* lose only some of the leaves.

Finally we have a good many trees shedding their leaves gradually while they are being replaced by new ones. An example is the *nim*. The formation of the absciss layer during the leaf-fall is discussed in Chapter 26.

Generally it is in the dry period that most trees lose their leaves, and this is often associated with the flowering period. This seems to facilitate pollination, since the new flowers are thus exposed to the agents of pollination.

The number of times in a year in which a tree will lose its leaves also varies. A number of them shed their leaves once a year, but others do so more than once a year. For example, *Albizia lebbeck* sheds its leaves twice a year while *Balanites* does so three times, and it is interesting to note that these periods are also the same as the periods of flowering in these trees.

Flowering and Fruiting Periods. It has been noticed that tropical plants vary in the number of times they flower in a year. In temperate climates most plants flower once a year, but in the tropics, because the weather is often suitable for plant growth throughout the year, a number of the plants flower more than once in a year. This is often associated with the fact that in a number of tropical areas there are two rainy periods, one of which is long and the other short. Among the trees which flower twice a year are the mango (*mangifera*) and cashew (*Anacardium occidentale*); among those which flower three times a year are the nim (*Azadirachta*) and *Balanites aegyptiaca*; among those that flower four times a year is *Terminalia catalpa*. Some also flower rather infrequently such as once in two or three years as in *Flacourtia flavescens* or even once in about five to seven years as in *Triplochiton*.

While the number of times of flowering is the same as the number of times of fruiting, there are a number of cases where fruiting fails to follow the flowering. Thus for example *Oncoba spinosa* flowers twice a year, once in the long rainy season and the other in the long dry season. But the flowering in the dry season does not lead to any fruiting. This is not to say that flowering in the dry season often fails to lead to fruiting, because trees that flower once a year often flower in the long dry period and almost invariably lead to successful fruiting. It is true to say, however, that trees which flower twice a year have their heavier flowering and fruiting in the one which falls close to the rainy season. Even plants which seem to flower through the year, such as *Spathodea* (tropical tulip tree) have a period during which flowering is heaviest and more conspicuous, and here it is during the short rainy season.

There is also an interesting relationship between flowering and the shedding of leaves. Among the plants which shed nearly all their leaves at a particular time some develop fresh leaves before the flowers become fruits (as in *Parkia* and *Antiaria*), while others develop fresh leaves only after seed dispersal has taken place (as in *Ceiba*). In some others, the new leaves are produced along with the flowers (as in *Terminalia* and *Milletia*).

Effect of Environment Factors. Observations show that environmental factors sometimes modify the flowering period. Thus *Haemanthus* which is typical of the savanna areas and flowers when the long dry period is just broken by the beginning of the long rainy period, may be found flowering in the forest canopy during the long dry period several months before the long rainy period starts. This is obviously due to the moist conditions of the forest canopy. Also *Delonix* which flowers in the long rainy period in most open vegetation can be found flowering in the dry period in the forest area away from the dry areas.

With these principles in mind, we shall try to give short accounts of some common tropical trees like the Mango (*Mangifera* sp.) flam-

boyant (*Delonix* or *Poinciana regia*), the coconut (*Cocos mucifera*) and silk-cotton (*Ceiba* or *Eridendron*) and tropical tulip tree (*Spathodea*).

The Mango (*Mangifera*)

General Morphology. The mango is a tree of medium size with a round crown. It thrives best in deep loamy soil and valleys, especially in the coastal regions, though in forest areas the fruits do not mature properly. The stem may give rise to branches near the ground, but there is often a distinct main trunk which is light brown in colour. The mango branches irregularly and the clusters of flowers are borne at the ends of the branches during flowering. The flowers are greenish white at first but later become pink. The fruit is a drupe (see Chapter 28) of characteristic shape, and ripens from green to yellow. It contains an edible pulp, from which a yellowish juice can be expressed, surrounding a single large 'stone'—the endocarp; inside the 'stone' lies the seed.

Leaves and Leaf-fall. The young leaves of the mango are brownish in colour but soon become light green and later gradually deepen in colour, becoming dull green when mature. The leaves are oblong and spear-shaped and are arranged alternately. They are often clustered near the tips of the twigs.

The mango does not shed all its leaves at one period, leaving the tree bare, but while in some countries, as in eastern Nigeria, different branches shed the leaves at different times, in many places the old leaves drop in large numbers when new ones have already been formed.

Flowering and Fruiting Cycles. In most tropical countries the mango has two flowering and fruiting periods in a year. One of these takes place at the end of the long dry period and the fruits are ripe in the early part of the rainy season. The fruits of this period are often attacked by certain butterflies which bore holes into the pulp and suck the juice. The other flowering period starts towards the end of the long rainy season and the fruits ripen during the beginning of the long dry period. Usually the fruiting at this period is heavier than the first one described above and the fruits are often free from the attacks of insects.

Flowering seems to be a little earlier in mango trees nearer the sea, and it also appears that branches exposed to the wind from the sea initiate flowering before the flowers sheltered from the sea wind.

Propagation. The mango is dispersed by animals, including man, who eat the pulp and drop the seeds about. The seeds lose their vitality quickly, so that it is best to plant them soon after their removal from the fruit.

The Flamboyant (*Delonix* or *Poinciana regia*)

General Morphology. The flamboyant, or flame tree, grows to a height of 10 to 15 m. It has a wide crown formed by the spreading branches. The main trunk is short and has a smooth, grey bark. The branches are irregular and similar in colour to those of the main trunk. Flamboyant is now grown in nearly every town and village in the tropics as an ornamental tree, owing to its bright scarlet flowers. The fruits are long pods. The tree thrives best in dry areas, especially near the shore.

Leaves and leaf-fall. The leaves are doubly compound with rather small, leathery leaflets. Nearly all the leaves are shed during the long dry period. The young leaves normally begin slowly to appear with the first few showers of rain at the beginning of the long rainy season. In wet forests the leaves may be present during the dry period.

Flowering and Fruiting Cycles. Flowering begins with the fresh leaves, but it appears to be at its peak when the long rainy season begins in full. At this time the bright scarlet and yellow colour of the flowers dominate the green colour of the leaves. The flowers attract insects which pollinate them as they come to suck nectar. The flowering and fruiting may continue through the long rainy season and sometimes the fruiting may also continue through the short rainy season. By the end of the rainy season no flowers are present but only the long pods, about $\frac{3}{4}$m long are found hanging on the trees. The pods are woody and contain about 30 to 40 seeds. Later these green pods change colour from green to brown and the dry fruits hang on the trees for about three months before they begin to drop to the ground. Even nine months after flowering, some of the dry old fruits still persist on the trees.

Propagation. The seeds of the flamboyant are dispersed as the pods dry out and split, scattering the seeds. The seedlings as well as fully grown plants are easily transplanted.

The Coconut (*Cocos nucifera*)

General Morphology. The coconut is a common tropical tree found chiefly along the sea-coast. It thrives in sandy and salty places. There is only one trunk or stem, which may become rather bent as it grows. The leaves, which are often wrongly spoken of as 'branches', are produced in a cluster. As the leaves fall off they leave rows of rather prominent leaf-scars on the trunk. The flowers are produced in large numbers on long yellow stalks. At the upper end of the inflorescence are the male flowers. These are far more numerous than the female flowers which are found at the lower end of the flower stalk.

The coconut is perhaps the most useful of all plants since virtually every part of it has some important use in the community. The fruit is a drupe (see Chapter 28) with fibrous tissue covering a hard kernel inside which is the 'milk' that is a refreshing drink, the husk is used in making cups, spoons, and other household articles.

The Silk Cotton Tree

General Morphology. The silk-cotton (*Ceiba pentandra* or *Eriodendron anfractuosum*) is a large tree with the branches arranged in horizontal whorls of three. The bark is white, and, when young, the bark of the trunk and branches is covered with thorns. The leaves are palmate. The trees are found in the forest as well as in the plains and can grow to become some of the largest trees in the evergreen forest. The wood is soft and white, and is used in making canoes. The oblong flowers are creamy-white and the fruits are large and covered with short hairs. They contain many seeds. Attached to each seed is a long cotton floss which arises from the wall of the ovary and the central axis.

Leaves and Leaf-fall. The silk-cotton tree sheds all its leaves during the short dry period and remains bare through to the beginning of the long dry period, when the flower buds appear. It remains bare when the fruits are formed, mature and the seeds are shed. After most of the leaves have been shed, new leaves again begin to form and these remain on the plant till they are shed again during the short dry period or at the beginning of the long dry period.

Flowering and Fruiting Cycles. The silk-cotton tree flowers and fruits once a year at the beginning of the long dry period. The flowers are pollinated by bats at night. The fruits mature and begin to burst to disperse the seeds which hang exposed in large white, woolly masses, giving a graceful look to the tree. It is a useful adaptation that the leaves are shed by this time because the cotton can then easily be carried away by the wind without becoming entangled in the leaves.

The white cotton is called 'kapok' and is used in stuffing pillows and mattresses. The seed itself is edible and contains oil.

Tropical Tulip Tree

General Morphology. The tropical tulip tree (*Spathodea campanulata*) is a medium-sized tree with a straight, pale-grey trunk and a bushy, tapering crown. The branches are directed upwards and the wood is soft. The dark-green leaves are compound and the tree is notable for its large red flowers which have the appearance of flames against the green background. The long, narrow fruits contain seeds each of which has a transparent wing which helps in its dispersal.

Spathodea is found in many tropical countries and thrives in deciduous and secondary forests as well as in the savanna. It is planted as an ornamental tree and for shade.

Leaves and Leaf-fall. The leaves are shed only gradually throughout the year to give place to new ones.

Flowering and Fruiting Cycles. The tulip tree flowers throughout the year but more heavily during the short rainy season. Soon the brown, hairy flower buds give rise to flowers with bright red colour which predominate during this period. In places north of the equator, this period falls a few months before December, and so farmers in West Africa associate this flowering period with the coming Christmas and the period for sowing the second crop of maize for the year. The flowering and fruiting however continue until the middle of the long dry period when the flowering passes its peak for a number of trees, although on others a few flowers continue to appear until the next heavy flush of flowering. Flowering and fruiting therefore continue virtually throughout the year.

Propagation. *Spathodea* is propagated by cuttings.

These descriptions of a few trees are meant to guide the student in making his own observations on them and on other trees in his area. The descriptions should therefore not be taken as applying to any particular locality.

SUGGESTED PRACTICAL WORK

1. Examine the parts of twigs of other deciduous perennial plants, such as *Terminalia*, *Ceiba*, or guava, just before the new leaves appear after becoming bare during the dry period. Make labelled drawings.

2. Select *one* of the following trees and make regular observations of any changes you observe in its morphology throughout the year, especially with regard to leaf-fall, flowering, and fruiting periods.

Lagerstroemia flos-reginae (queen of flowers), *Samanea saman* (rain-tree), *Artocarpus integrifolia* (jack fruit) and *Cassia siamea*.

3. Collect a specimen of an annual plant such as *Vernonia* from waste-ground and make a well-labelled drawing of it.

4. (*a*) Visit a botanical garden and examine various kinds of trees. Learn the names of the trees you examine.

(*b*) Make a plan of the school compound and represent each tree and shrub by means of appropriate symbols. Identify as many trees and shrubs as possible, and then label them by painting their names on small boards placed near the plants.

(*c*) Take bark rubbings from as many different kinds of tree as possible. To take a bark rubbing, place a sheet of clean paper on the trunk of a tree and rub the paper with the side of the lead of a 'soft' pencil (as though you were 'shading'). After covering the surface of the paper in this way, it should be possible to see the pattern of the underlying bark on the sheet of paper.

CHAPTER TWENTY-FOUR

The Stem and Vegetative Reproduction in Flowering Plants

THE stem of a flowering plant bears the leaves. Together, stem and leaves make up the *shoot*. The leaves may be rather reduced, but there are always signs of them at the nodes. The stem also has a bud in the axil of the leaf, in addition to the terminal bud. It is always possible to distinguish a stem from a root because the stem will always show traces of leaves and buds. The stem may also bear flowers and fruits, but since these are not always present they are not reliable characteristics by which to identify the stem. In the internal structure, we have other distinct differences between the stem and the root, as will be shown later.

We have already considered the functions of the stem in Chapter 23.

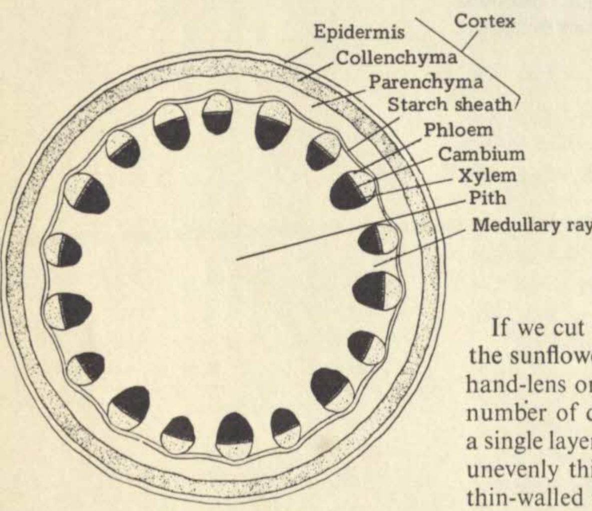


Fig. 24.1. Transverse section of sunflower (dicotyledon)

Internal Structure of the Stem

If we cut a section of a young herbaceous dicotyledon stem such as the sunflower (Fig. 24.1) and, after staining, examine it by means of a hand-lens or the low power of the microscope, we find that there are a number of distinct layers of tissues. On the outside we first of all find a single layer of cells called the *epidermis*. Inside this is a broader layer of unevenly thick-walled cells called *collenchyma*, followed by a layer of thin-walled cells called *parenchyma*, and a much thinner layer of cells containing starch grains called the *starch sheath*. These three layers just within the epidermis form the *cortex* and the cells have air spaces between them. The cells in the cortex contain chloroplasts which colour the stem green. Chloroplasts are essential in photosynthesis.

We then come to the ring of *vascular bundles* inside the starch sheath. Each vascular bundle consists of the *phloem* tissue on the outside, a thin layer of *cambium*, and the *xylem* tissue. The phloem consists of cells which are concerned with transporting food substances, *e.g.*, from the leaves after photosynthesis to other parts of the plant. The cambium is a tissue of growing or actively dividing cells. The xylem is the tissue concerned with one of the most important functions of the stem, that of carrying water and salts from the root to the leaves; it contains wood vessels for this purpose.

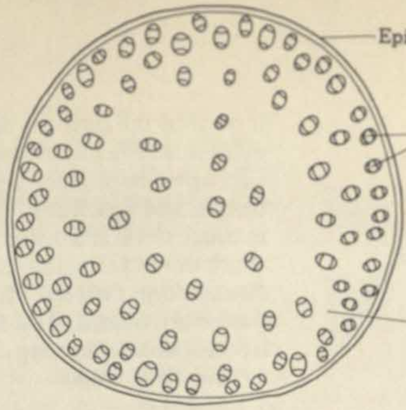


Fig. 24.2. Transverse section of maize (monocotyledon)

Between the vascular bundles are the cells forming the *medullary rays* which contain air spaces to permit the exchange of gases with the atmosphere during respiration. The arrangement of the vascular bundles in an outer ring in the stem is of advantage to the plant, since it provides mechanical support for the upright stem. The large central part of the stem consists of large cells forming the *pith*, but in some cases a hollow space is present.

It should be mentioned here that in monocotyledons, such as maize (Fig. 24.2), the vascular bundles are not arranged in a ring, but are scattered throughout the stem; here these bundles have no cambium and the stems seldom increase in thickness. There is also no central pith and the cortex is very narrow.

Secondary Growth or Thickening in Stems

In dicotyledons, unlike the monocotyledons, a layer of actively dividing cells (the cambium) is found between the xylem and the phloem, and growth in thickness of the stem takes place by a process known as *secondary thickening* (Fig. 24.3). In this process new xylem or *wood* is

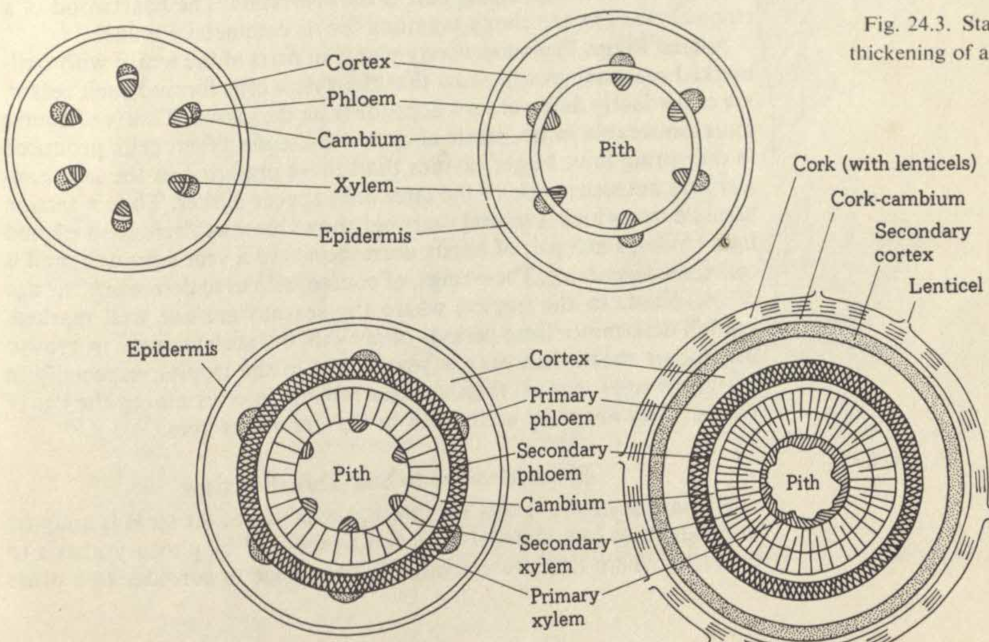


Fig. 24.3. Stages in secondary thickening of a dicotyledon stem

formed by the cambium on its inner side, and new phloem or *bast* on its outer side. The process may go on until the stem grows to an enormous size, as in trees. Later a new layer of cambium appears under the epidermis, and proceeds to form new cortex on the inside and *cork* on the outside. Cork is a tissue which consists of dead and thickened cells, which are impermeable to water so that all the tissues outside the cork die and form the *bark*. This cuts off the connection of the stomata with the inner tissues, and the function of the stomata is taken over by ventilation spaces, consisting of rounded cork cells in the bark, called the *lenticels* (Fig. 24.4).

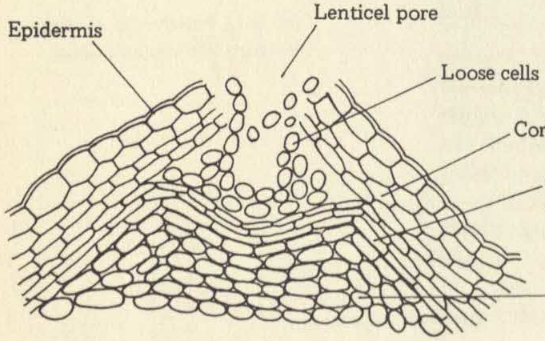


Fig. 24.4. Transverse section through a lenticel

Sapwood and Heartwood. As many rings of xylem or wood are produced from year to year in big trees, it is only the outer and younger layers of the wood which continue to conduct water and salts to the leaves. This outer conducting wood is called the *sapwood*, while the darker and older supporting part is the *heartwood*. The heartwood of a tropical tree like the ebony accounts for its commercial value.

Annual Rings. Perennial woody plants in parts of the world with well-marked seasonal growth show that the xylem cells formed each season are of distinctly different sizes depending on the season. This is of course more noticeable in temperate climates where the xylem cells produced in the spring have bigger cavities than those produced in the late summer and autumn; areas of the later cells appear darker. Thus a section across a tree which is several years old shows these as alternate dark and light circles. Each pair of bands corresponds to a year's growth, and is called an *annual ring*. These rings, of course, help us to determine the age of the plant. In the tropics, where the seasons are not well marked, rainfall determines these periods of growth, but such changes in growth may occur more than once a year. Thus in the tropics, especially in evergreen trees, annual rings are less reliable in determining the age of plants. They are more easily seen in the deciduous trees.

Stems Modified to Suit Their Functions

We have seen above how the internal structure of the stem is adapted to conducting raw materials and food produced by photosynthesis to the parts where they are needed. We now come to consider two other

functions and to see how various stems are modified to these ends. The first of these is that of holding the leaves in positions where adequate sunlight can be obtained for photosynthesis, and the second is that of storing water and food substances. The modifications of stems for these functions also make them suitable for vegetative reproduction.

Modifications to Hold Leaves in Sunlight. A number of aerial stems are strong enough to stand erect and have no great problem in holding the leaves to sunlight, although when overcrowded they tend to grow rather taller in order to reach it. Some other stems, however, are too weak to stand upright by themselves and so they either climb up erect stems or supports by means of various modifications of their own stems or branches (*climbing plants*), or they trail on the ground (*creeping plants*).

Among the climbing plants we have (*a*) the *twiners*, which are herbaceous climbers, (Fig. 24.5) such as the beans or species of *Ipomoea* (such as morning glory or the sweet potato) or species of yams (*Dioscorea*); (*b*) *lianes*, or *woody climbers*, common in tropical forests, such as *Landolphia* and some species of *Ficus*; (*c*) *stem tendrils*, which are usually axillary branches modified into thread-like and leafless structures to aid in clasping the support during climbing. Examples of these are *Passiflora* (such as the passion flower), *Guania*, *Coralita*, and *Antigonon* (Fig. 24.6); (*d*) *thorns* (or hooks), which are also modified branches, as in *Bougainvillea* and *Duranta* (Fig. 24.7).

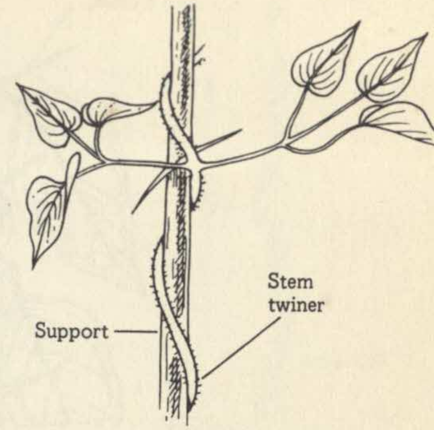


Fig. 24.5. A twiner: yam

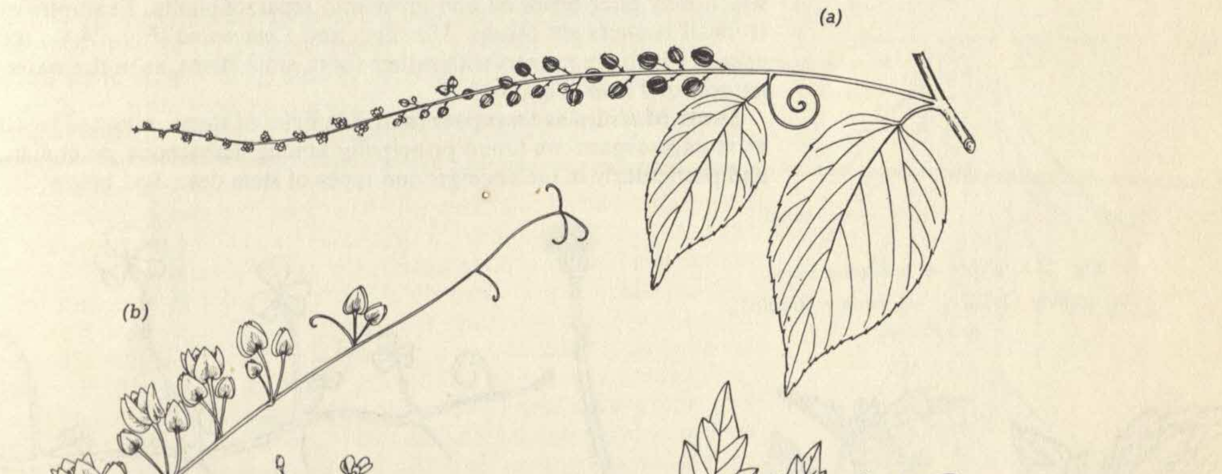


Fig. 24.6. Stems modified as tendrils: (*a*) *Guania*; (*b*) *Antigonon*; (*c*) *Cardiospermum*

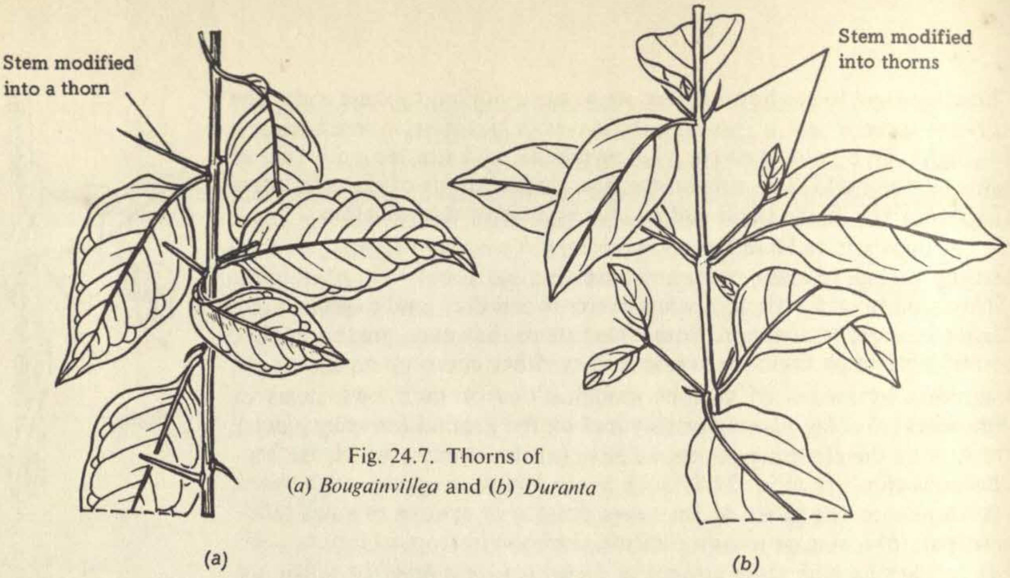
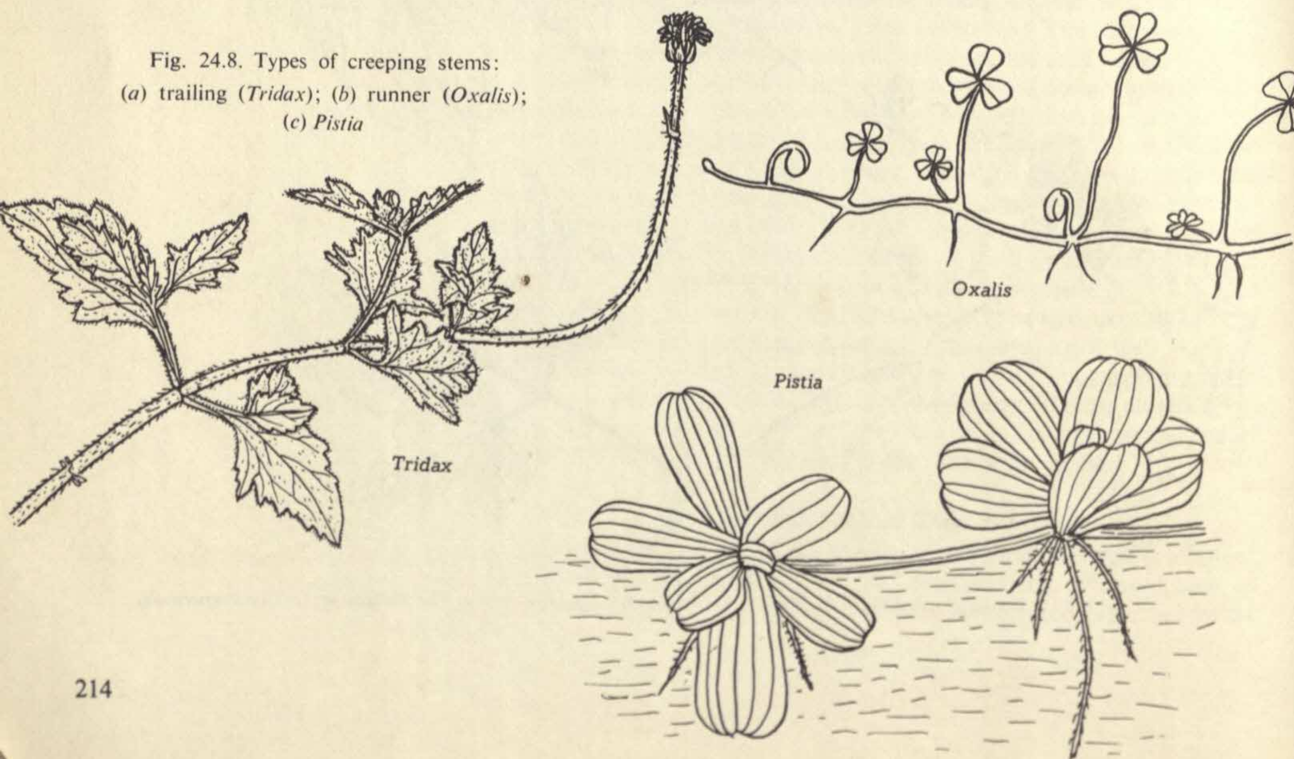


Fig. 24.7. Thorns of (*a*) *Bougainvillea* and (*b*) *Duranta*

When we come to the creeping stems we have (*a*) the *trailing stems*, which creep on the ground without being rooted at the nodes. Examples of these are found in *Portulaca*, *Tridax* (Fig. 24.8), and *Boerhaavia*; (*b*) *runners*, which root at the nodes and send out new upright branches which may later break off and grow into separate plants. Examples of tropical runners are *Oxalis*, *Marsilea*, and *Commelina* (Fig. 24.8); (*c*) *offsets*, which are runners with rather short, stout stems, as in the water-lettuce, or *Pistia* (Fig. 24.8).

Stems Modified as Storage-organs. Examples of stems modified to act as storage-organs are found principally among herbaceous perennials, and particularly in the underground types of stem described below.

Fig. 24.8. Types of creeping stems: (*a*) trailing (*Tridax*); (*b*) runner (*Oxalis*); (*c*) *Pistia*



Storage of water in the stem is carried out in different types of cactus such as *Opuntia*, or the cactus-like poinsettias (*Euphorbia*) (Fig. 24.9). Here the leaves are much reduced or are modified into spines. Such plants live in dry situations and the stems, which have taken over the function of the leaves—*i.e.*, photosynthesis—also have to prevent the loss of too much water by transpiration in dry weather. Thus the stems are thick and store water in their tissues (Fig. 24.9).

The storage of food substances in stems enables many herbaceous plants to survive from year to year. These are usually underground stems modified in various ways into structures known as the *rhizome*, the *stem tuber*, the *corm*, the *bulb*, and the *sucker*. A number of these look like roots but they bear scale-leaves and axillary buds, and are therefore clearly stems. Like the creepers, they are also adapted for vegetative reproduction.

A *rhizome* (Fig. 24.10) is a thickened stem, creeping horizontally underground, and usually containing stored starch. It bears scale-leaves with axillary buds at the nodes. The terminal bud grows out into an aerial shoot and may produce flowers. Normally the rhizome reproduces vegetatively. In that case axillary buds grow into branches and may separate off and grow into independent plants when the old parts of the rhizome die. After the flowering season, the aerial shoots die down every year leaving large *scars*. In the following year growth is started again by one or more lateral buds. Examples are the ginger and *Canna*.

A *tuber* (Fig. 24.11) is the swollen end of a branch of a special underground stem. It also stores starchy food materials. Tubers should not be confused with tuberous roots (Chapter 25). As a stem structure the tuber is found to bear buds in scale-leaves which appear as 'eyes' on

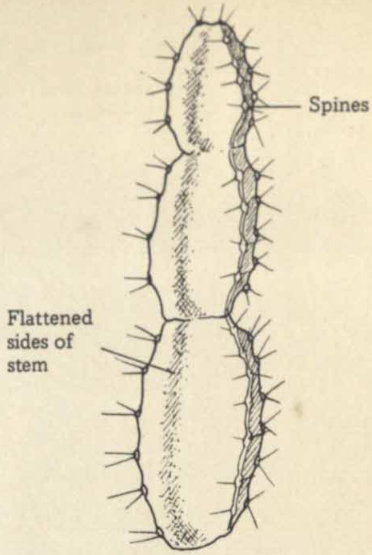


Fig. 24.9. Structure of *Euphorbia*

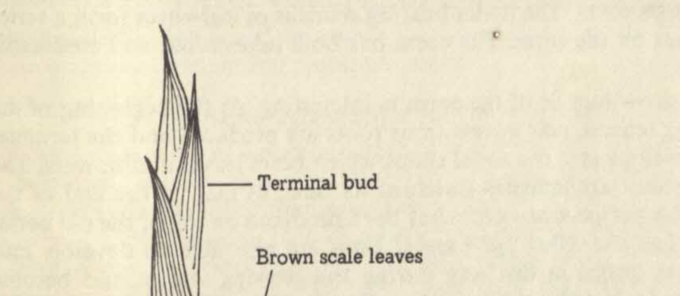


Fig. 24.10. A rhizome: *Canna*

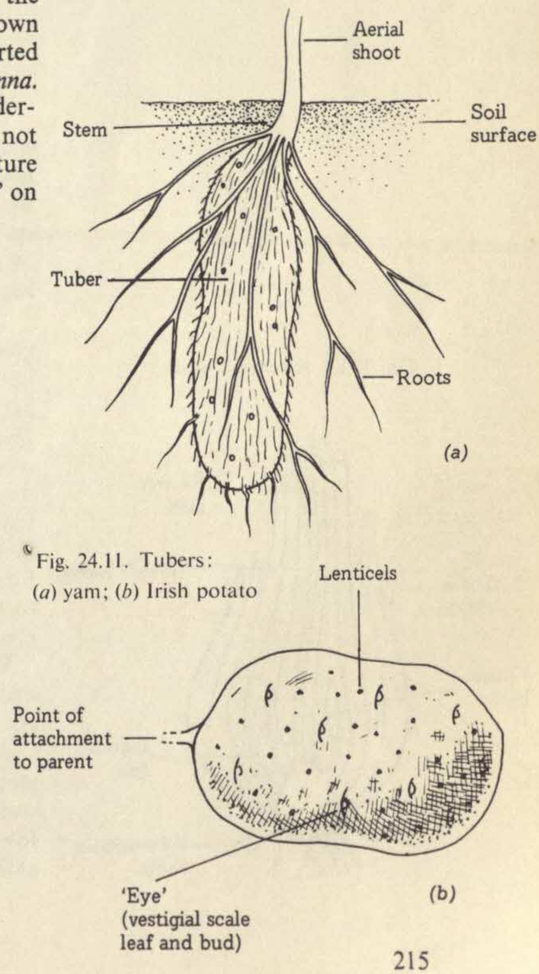


Fig. 24.11. Tubers: (*a*) yam; (*b*) Irish potato

the tuber. The tiny buds are capable of growing into new plants, so that slices of tubers (which must bear buds) may be used for propagation. Tubers do not grow continuously as do rhizomes, but normally last for a short time, and new tubers are produced as the main plant grows. The potato (Irish potato), the yam (*Dioscorea*), tiger nuts, and the Jerusalem artichoke are examples of stem tubers.

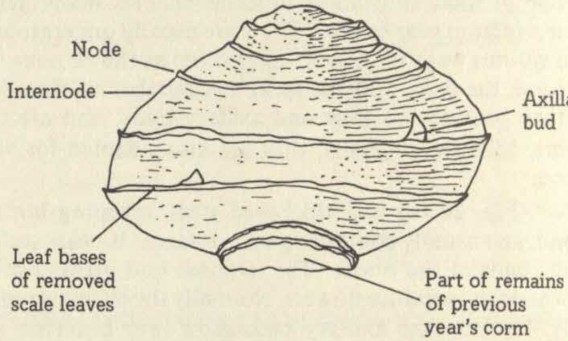


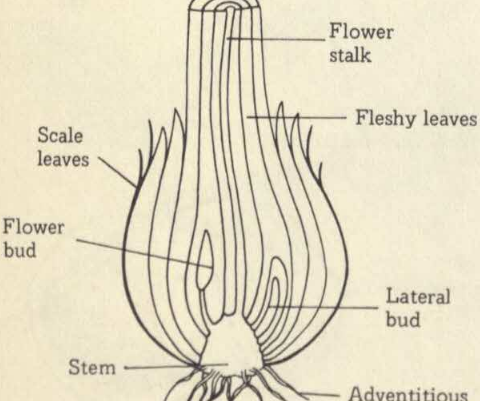
Fig. 24.12. A corm: gladiolus with scale leaves removed

A *corm* (Fig. 24.12) is a swollen, solid, fleshy underground main stem which grows vertically, and looks like a condensed form of rhizome. It contains a heavy deposit of starch, and is more or less rounded in shape, but may be flattened from top to bottom, as in species of gladiolus and the crocus corm. The nodes bearing remains of leaf-bases form a series of ridges on the corm. The corm has both *adventitious* and *contractile roots*.

The growth-cycle of the corm is interesting. At the beginning of the growing season, new adventitious roots are produced and the terminal bud develops into the aerial shoot which bears leaves and flowers. The aerial shoot accumulates starch at its base, so that by the end of the flowering period a new corm has been produced on top of the old corm, which has shrivelled up. Lateral buds are also able to develop into daughter corms in this way during the growing season and become separated when the old corm dies. By the next growing season the terminal bud of the new corm develops into a flowering shoot which also forms a corm at its base. The process is repeaed for some years and, to prevent the new corms from appearing above the ground, the thick contractile roots keep pulling the corms down into the soil.

Well-known examples of corms are species of gladiolus, *Caladium*, and saffron (crocus corm). The cocoyam (*Xanthosoma*) produces small corms around the outside of the old one.

Fig. 24.13. A bulb: *Crinum*



A *bulb* (Fig. 24.13) is a much shortened or reduced underground stem. It consists of a short plate of stem, the *disc*, bearing large, fleshy, overlapping leaf-scales on its upper surface and adventitious roots below it. The terminal bud of the bulb gives rise to the aerial shoot, while axillary buds may be produced on the stem in the axils of the fleshy

scales. Just after the dry season one of the axillary buds grows and becomes the bulb of the following year. Some of the daughter bulbs may be detached and grow into separate bulbs.

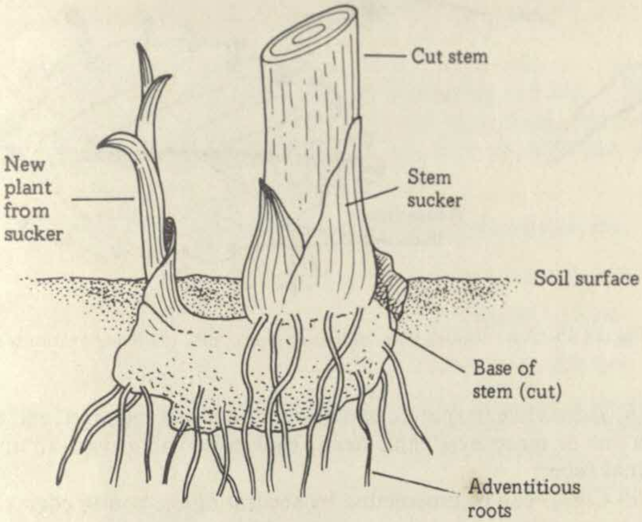


Fig. 24.14. A sucker of banana shoot

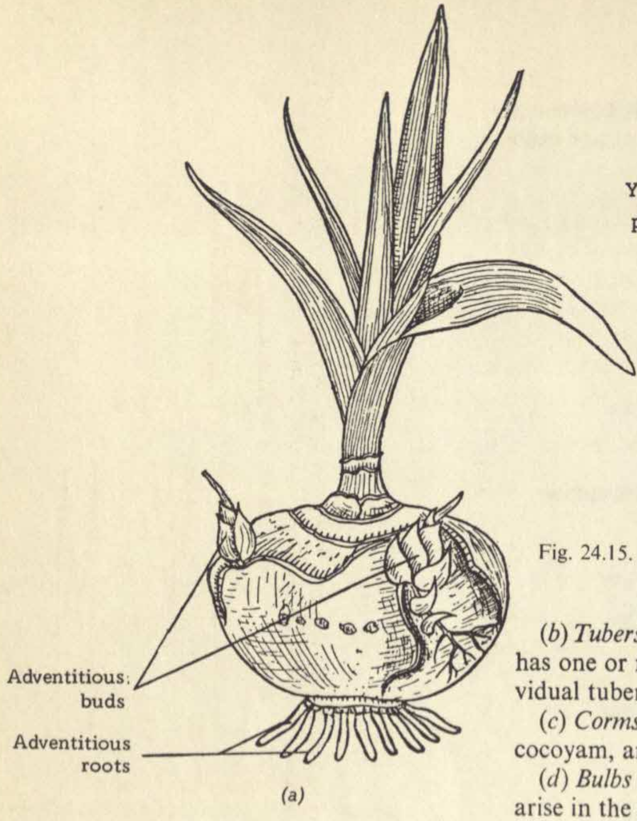
A *sucker* (Fig. 24.14) is a short, horizontal branch of a stem, just below the soil, with a terminal bud which grows upwards and develops roots and aerial shoots. Suckers have a root-like appearance but they bear scale-like leaves and are usually thick with food reserves. Examples are plantain, banana, and pineapple suckers.

Vegetative Reproduction in Flowering Plants

When a portion of a plant is detached and grows into an independent individual, we say that vegetative reproduction has occurred. This method is distinguished from sexual reproduction by seed (Chapter 27). We saw that vegetative reproduction occurs with all the underground storage organs described above; it also occurs with runners. Man has used his knowledge of buds and their behaviour to invent methods of vegetative reproduction. Finally, certain storage leaves are also able to propagate the plant vegetatively. Some of the modes of vegetative reproduction will now be discussed.

1. Separation of Portions of Food-storage Organs of Herbaceous Perennials. These organs are the rhizomes, tubers, corms, bulbs, and suckers described above. In each case, as the older parts die away, new plants are formed from the parts which are left. Their success in this is due to the fact that suitable pieces of these structures are able to develop into separate plants. It is worth emphasizing these methods of artificial vegetative propagation.

(*a*) The *rhizome*, such as the ginger, can be divided into lengths, and propagated.



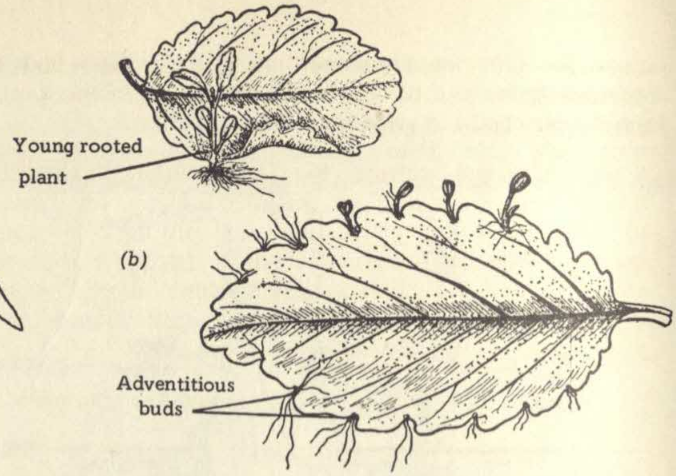


Fig. 24.15. Adventitious buds on (*a*) *Urginea* bulb; (*b*) *Bryophyllum* leaf

(*b*) *Tubers* like the potato can be cut into pieces such that each piece has one or more 'eyes', and sown; each piece will grow into an individual tuber.

(*c*) *Corms* can be propagated by separating the young corms, as in cocoyam, and growing them separately.

(*d*) *Bulbs* are also propagated by separating the young bulbs which arise in the axils of the scale-leaves as in *Crinum*, or the adventitious buds (see below) on the scale-leaves as in some tropical varieties of *Urginea* (Fig. 24.15).

(*e*) *Suckers*, as in the plantain and the banana, can be separated and grown individually and each is able to develop into a separate plant.

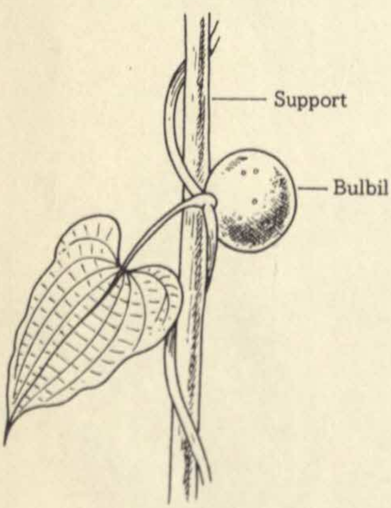


Fig. 24.16. Bulbils of *Dioscorea*

2. Creeping Stems. In creeping stems, as in *Ipomoea*, which root at the nodes, the internodes often die and new plants arise at the nodes.

3. Adventitious Buds on Leaves. Mention has already been made under 1(*d*) of a case of adventitious buds on the scale-leaves of some *Urgineas*. In *Bryophyllum* (Fig. 24.15), *Kalanchoë*, and similar plants, a series of buds is produced on the leaves, each at the end of a vein. Each of these buds may become detached and grow into a new plant.

4. Bulbils. (Fig. 24.16.) These are vegetative or floral buds in leaf-axils and are modified for the vegetative reproduction of the plant, particularly where seed formation is uncertain. They drop from the mother plant to the ground and grow into new independent plants. They are commonly found in some types of wild yam (*Dioscorea*), where globose bulbils of various sizes occur as fleshy axillary bodies. In the pineapple, the inflorescence which forms the large fruit generally ends in one or more reproductive buds, each of which can develop into an independent plant.

Artificial Propagation

This consists of applying our knowledge of natural vegetative reproduction as shown below.

(*a*) **Cuttings.** Lengths of stems of many perennial plants when planted in the ground produce adventitious roots and grow into new plants.

There are numerous examples, including not only plants like the herbaceous fleshy prickly pear (*Opuntia*), but also woody plants like the cassava or manioc, and roses.

(*b*) **Budding and Grafting.** (Fig. 24.17.) Budding is carried out by cutting out a young axillary bud (the *scion*) from one plant in such a way as to include part of the outer tissues, especially the cambium, and inserting it in a T-shaped incision made in another plant, the *stock*. The two are then bound firmly until their tissues unite. In *grafting*, two pieces of shoot from different plants are bound together, one (the *scion*) being attached to the stock, which bears the roots.

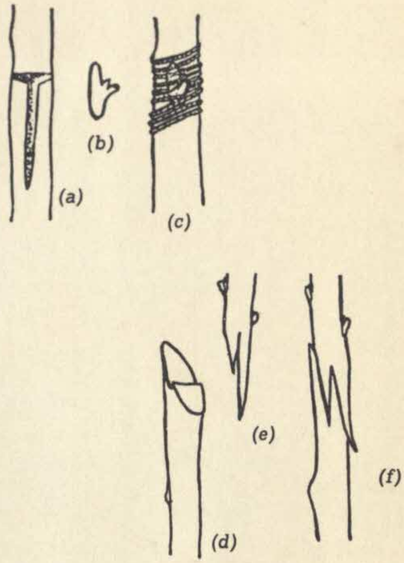


Fig. 24.17. Budding and grafting: (*a*) stock; (*b*) bud scion; (*c*) bud graft; (*d*) stock; (*e*) shoot scion; (*f*) graft

Comparison of Vegetative and Sexual Reproduction by Seed

Vegetative	*Sexual by Seed*
A. Advantages	**A. Disadvantages**
1. Offspring are uniform, which is an advantage if the plant is well adapted to its environment.	1. Offspring are not uniform. All of them, therefore, cannot be well adapted to their environment.
2. Only a single plant is necessary, and since many plants can be produced from one individual this is very useful in the artificial propagation of sterile plants, for example, the seedless orange.	2. Two parents are required.
3. No pollinating agent is necessary.	3. An external pollinating agent is often necessary.
4. This method of reproduction is only limited by the food supply and the offspring are produced and mature more quickly. The plant, therefore, spreads faster.	4. Seed can often only be produced at special stages in the life-cycle or during the year. The offspring develop more slowly and hence the spread of plants is slower.
5. The young plant obtains food from the parent over a long period and can, therefore, survive adverse conditions more easily.	5. The food supply of the seed is limited and germinating seeds very often die under adverse conditions.
B. Disadvantages	**B. Advantages**
1. Dispersal is often very limited which results in overcrowding and competition for nutrients and light.	1. Dispersal over long distances is possible. Short-distance dispersal can, however, also result in overcrowding.
2. Disease is often transmitted from one generation to the next.	2. Disease is rarely transmitted from one generation to the next.
3. Since all the offspring are uniform there can be no evolutionary advance, and if the plants are badly adapted to their environment they may die out altogether.	3. Since the offspring are varied evolutionary advance can occur. If the environment becomes unfavourable the chances of survival are higher than for plants reproducing by vegetative methods.

SUGGESTED PRACTICAL WORK

1. *Bud structure*. The cabbage (*Brassica oleracea*) starts off as an axillary bud which continues to grow after its subtending leaf has dropped off, so that it becomes a very large resting bud and appears terminal. Examine its structure by cutting through it. Note the bud axis or stem, the shape of its apex and the rudimentary leaves with their axillary buds.

The onion bulb is really a telescoped shoot and should be investigated since its structure is very much like that of a bud. The bulb is specialized in that it has a short, squat stem which bears buds and thick, fleshy leaves.

Observe carefully the shape, and arrangement on the stem, of the buds of various trees in the compound; pay particular attention to the terminal portions of branches of frangipani.

2. Your teacher will cut transverse sections of a young stem of the sunflower (*Helianthus*) and stain them. Examine one of them with the aid of a hand-lens, and note that the section is sufficiently enlarged to show a ring of distinct vascular bundles with a narrow zone outside (the cortex) and a wide solid central core of pith. The outermost layer of cells (the epidermis) may bear hairs. Make a drawing of the distribution of tissues.

Also look at the section under the microscope and note the varying structures of the cells making up the different tissues.

3. Examine the external and internal features of some of the local examples of perennating organs like a rhizome, a tuber, a corm, a bulb, and a sucker and make well-labelled drawings.

4. The next time you visit a botanic garden or an agricultural station ask to be shown a grafted plant. Try to discover the names of the varieties used as stock and as scion in propagation of *Citrus* species.

CHAPTER TWENTY-FIVE

Roots and Their Structure

THE main functions of the root, as mentioned in Chapter 23, are those of holding the plant firmly and absorbing water and dissolved salts, as well as oxygen in solution, from the soil. Experiments to illustrate these functions are described in Chapter 30. To fulfil these functions, roots normally have to grow through the soil, where they meet a great deal of resistance. Their delicate tips are therefore protected by means of a cup-shaped layer of tissue known as the *root-cap*. Behind the root-cap the root has numerous delicate hairs known as *root-hairs* which grow between the particles of the soil and thus help the branch roots to hold the plant firmly (Fig. 25.1). The more important function of the root-hair is the absorption of water and dissolved salts from the soil. Root-hairs live for only a few days, after which they are replaced by new ones. They are outgrowths from single surface-cells of the root.

Root-hairs and root-caps are clearly seen in that tiny water-plant the duckweed (*Lemna*) (Fig. 25.2), the roots of species of *Ficus* (e.g. banyan), which hang in the air or spread on a wall or another tree, and the stilted aerial roots of the screw-pine (*Pandanus*).

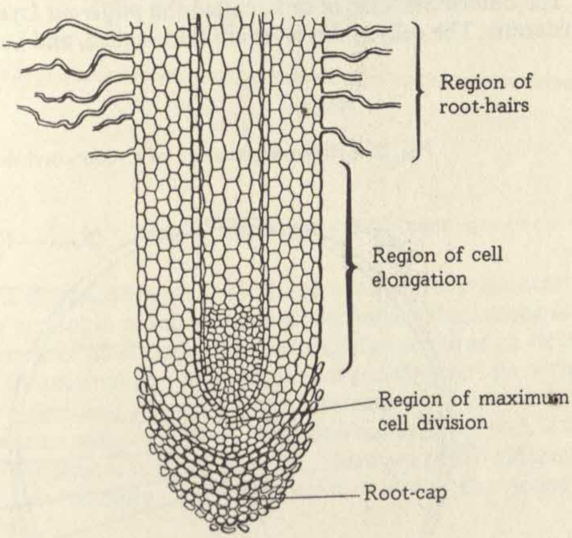


Fig. 25.1. Root-tip showing root-cap, hairs, and other parts

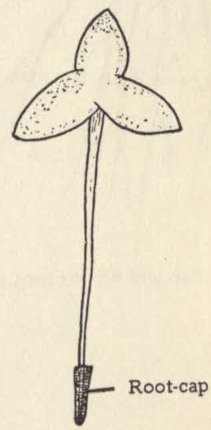


Fig. 25.2. *Lemna*, showing root-cap

Roots of any type can be distinguished from stems because they do not bear leaves or buds, and thus lack internodes; instead, they have root-caps and root-hairs at their tips. Internal structure, to be discussed below, also shows other differences between roots and stems.

Types and Shapes of Roots

There are two types of roots. These are called *true roots* and *adventitious roots*, depending on their origin. During the germination of a seed (Chapter 29) the radicle arises as the first root and, by definition, this is the *true root*; any branch root that arises from the true roots is part of the true root system. But roots may also arise elsewhere on a plant, and such roots are called *adventitious* roots. They are found, for example, at the base of the stem of a maize plant, at the nodes of creeping plants like the *Oxalis*, or on leaves, as in *Bryophyllum* (Fig. 24.15).

If in the true roots the first one continues to grow bigger than any of its branch roots, as for example in *Vernonia* (Chapter 23), it becomes a *tap-root*. Together with its branch roots this forms a *tap-root system* (Fig. 25.3) which is typical of plants with two seed-leaves, or cotyledons (Chapter 29), called *dicotyledons*. If, on the other hand, the branch roots grow to about the same size as the first root, along with other roots from below the stem, so that it is not easy to distinguish the first root, then a *fibrous root system* (Fig. 25.3) results. This is commonly found in plants with only one cotyledon (*monocotyledons*), such as maize and the grasses.

Internal Structure of Roots

A transverse section of the root of a young herbaceous plant, like the sunflower or *Vernonia* (Fig. 25.4), when viewed under the microscope shows a wide outer region, the *cortex*, and an inner *central core* composed of the tissues of the vascular bundle.

The outermost layer of cells, called the *piliferous layer*, represents the epidermis. The cells of this layer are thin-walled, and here and there it is

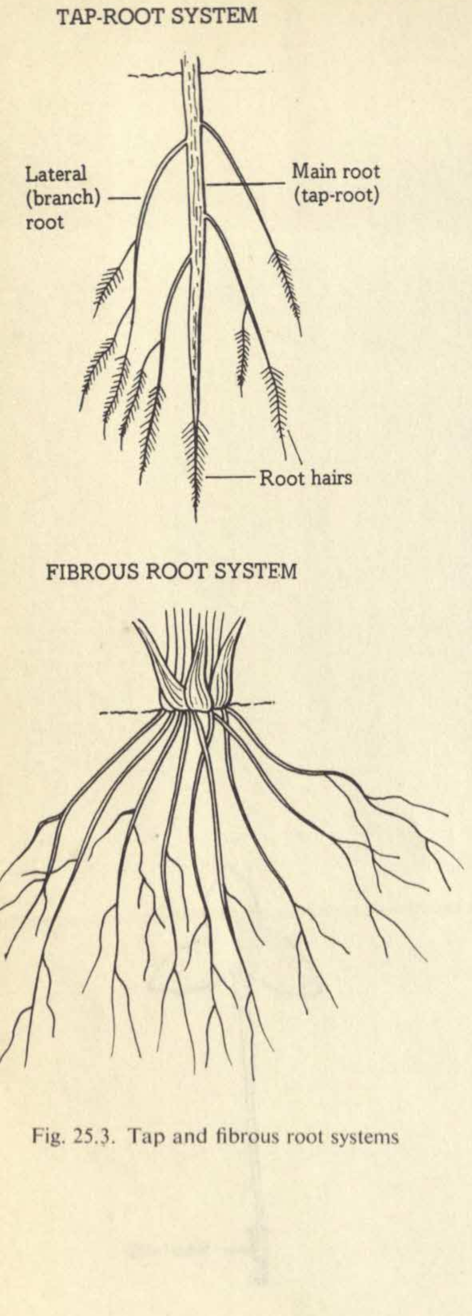
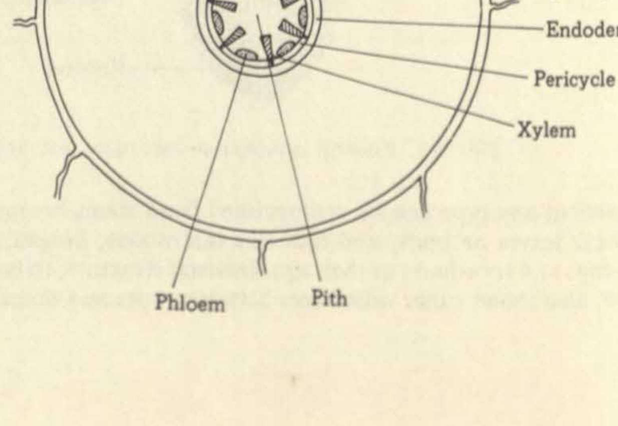


Fig. 25.3. Tap and fibrous root systems

Fig. 25.4. Internal structure of a monocotyledon root (with pith)



found that some of these cells have grown into long projections which are the root-hairs. Inside the piliferous layer are the cells of the cortex proper. These are large, thin-walled cells with intercellular spaces through which exchange of gases takes place during respiration.

Just before the inner core, the cells of the cortex are found to be particularly specialized. They are elongated without intercellular spaces but with dark-staining thickenings round the middle of their radial walls. These cells form the *endodermis*.

The central core inside the endodermis consists of star-shaped xylem tissue, and phloem tissue between the rays of the xylem. The phloem tissue is separated from the xylem tissue by thin-walled cells.

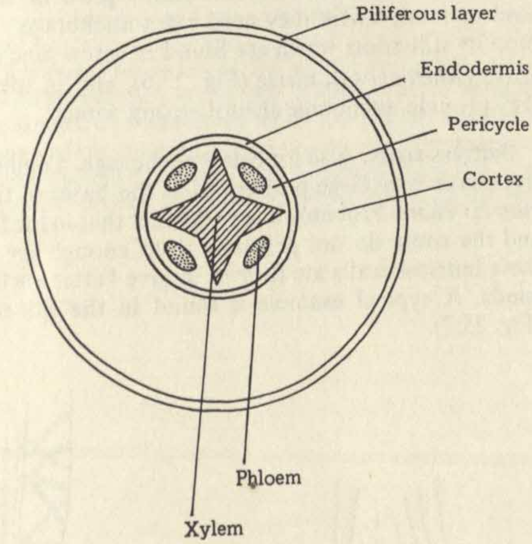


Fig. 25.5. Internal structure of a dicotyledon root (no pith)

In the roots of dicotyledons (Fig. 25.5), there is no pith in the central core, but pith is present in monocotyledons. Secondary thickening also takes place in roots of dicotyledons in ways similar to those in stems. Comparison of the internal structure of the root and the stem show that in the root the xylem and phloem tissues alternate while in the stem these are on the same radii. Secondly, the widest tissue in the root is the cortex, while in the stem it is often the pith. There are other differences which concern cell structure, but these are not within the scope of our present study.

Roots Modified for Different Functions

Apart from the two main functions of roots mentioned above, certain roots are specially modified for other functions such as climbing or food-storage. Some of these modified roots are discussed below.

Tuberous Roots for Food-storage. Although most ordinary roots normally store some food reserves, in certain plants the food reserve,

which is principally starch, is in such large quantities that the roots concerned grow into large swollen structures called *tuberous roots.* Much of the food is stored in the cortex, while the conducting tissue is much reduced. Typical tropical examples are the cassava or manioc, and the sweet potato; in these the storage-roots are adventitious and store starch. The carrot stores sugar in its tap-root.

Contractile Roots. We described these as being strong roots, found on corms such as gladiolus (Fig. 24.12), which help to pull the new corms into the soil to prevent them from appearing on the surface. These roots thus help in proper anchorage of the plant.

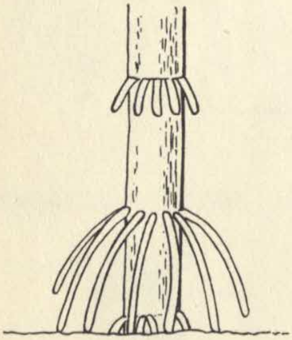


Fig. 25.6. Prop-roots of maize

Prop and Stilt-roots. Certain plants grow in situations, such as in sand or mud, where they need extra anchorage. This is provided by prop or stilt-roots which are found in screw-pine (*Pandanus*), red mangrove (*Rhizophora*), maize (Fig. 25.6), and in species of *Ficus*, where they provide anchorage against strong winds.

Buttress-roots. Also for better anchorage, a number of tropical forest trees have very large projections at the bases of the main roots, called *buttress-roots.* Probably due to the fact that in the forest the soil is damp and the roots do not penetrate deep enough for these very tall trees, these buttress-walls are formed to give better anchorage against strong winds. A typical example is found in the silk-cotton tree, or *Ceiba* (Fig. 25.7).

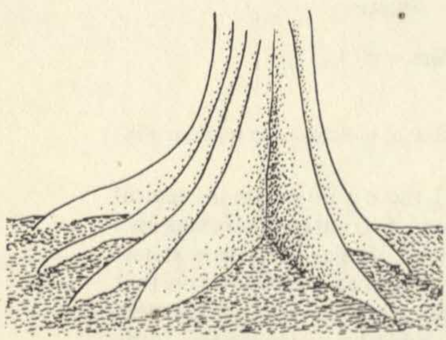


Fig. 25.7. Buttress-roots of silk-cotton

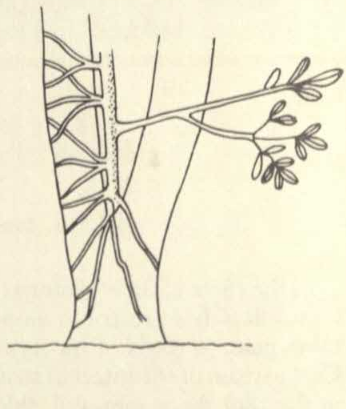


Fig. 25.8. Climbing roots of epiphytic fig

Climbing and Aerial Roots. Many epiphytic plants (Chapter 2) produce roots which help in securing attachment to the bark of the tree on which they grow. In some cases there are other *aerial roots*, which absorb drops of water as they run down the tree. Such roots are also green with chlorophyll and carry out photosynthesis. Orchids and species of *Ficus* (Fig. 25.8) are examples of plants with aerial or climbing roots.

SUGGESTED PRACTICAL WORK

1. Dig up seedlings of *Vernonia* and corn and compare the nature of their roots.

2. Germinate some maize seeds or bean seeds, and after about four days observe the root-cap and the root-hairs, using a hand-lens if necessary.

The next time you visit the beach, look for a screw-pine (*Pandanus*) and observe its large stilt-roots and the prominent root-caps.

3. The teacher will cut a section of the root of the sunflower or a bean, stain it, and mount it under the microscope for you to examine. Using the low power of the microscope, study the distribution of the tissues, and make a drawing of them.

4. Make drawings of local examples of tuberous and contractile roots. Visit a botanic garden to see examples of prop, buttress, and climbing roots.

5. From what you have learnt about the roots so far, try to study how the root is adapted for its functions: for example, for holding the plant, notice that the root branches and spreads in the soil, and its central wood helps in overcoming the pulling strains. For absorbing water the branches and the root-hairs provide a large surface, their walls have no cuticle to hinder entry of water, and their semi-permeable cytoplasm and the concentrated sap help water to enter by osmosis. Consider the other functions and find out the necessary adaptations.

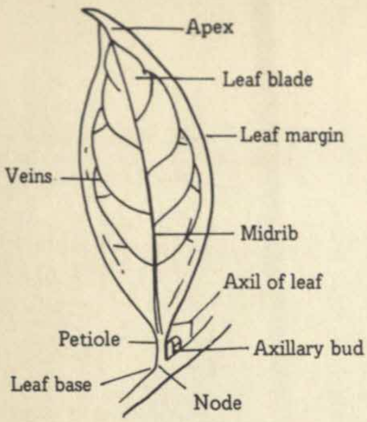


Fig. 26.1. Parts of a foliage leaf

CHAPTER TWENTY-SIX

Leaves and Their Structure

NORMALLY when we speak of the leaf we mean the ordinary green leaf, or *foliage leaf*, whose main function is the manufacture of food for the rest of the plant by the process of photosynthesis (Chapter 23). The leaf also loses water to the atmosphere (transpiration). The leaf grows at the node of a stem and has a bud in its axil.

Parts of a Leaf

A typical green leaf (Fig. 26.1) consists of three principal parts, the *leaf-base*, the *petiole*, and the *leaf-blade* (or lamina). The leaf-base is the part of the leaf attached to the stem; it may bear two structures at the sides called *stipules*, as found in a dicotyledon like the rose, or expand into a sheath, as in monocotyledons like the banana or grasses. The petiole is the stalk between the leaf-base and the leaf-blade, but it is absent in the leaves of some plants, like the *Zinnia* and apple of Sodom (*Calotropis*). The leaf-blade, or lamina, is the green, flattened part of the leaf. In the centre is a strong vein known as the *midrib*, which gives rise to the *secondary veins* at its sides. Leaves of dicotyledons are *net-veined*, while those of monocotyledons are *parallel-veined* (Fig. 26.2).

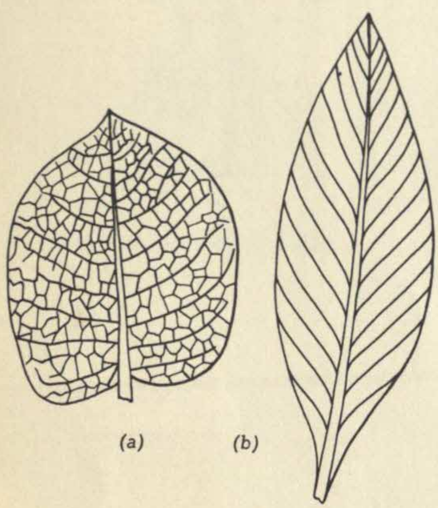


Fig. 26.2. (*a*) net; (*b*) parallel venation in leaves

Shapes of Leaves

There are *simple* and *compound* leaves. A simple leaf is in one piece, that is, it has one leaf-blade, and even when the margin is irregular or divided, the portions are not wholly separated at the original midrib. A compound leaf, on the other hand, has its separate portions (called *leaflets*) separated at the original midrib so that each of them has a separate stalk; but all of them are attached to a common leaf stalk. Simple leaves are found in plants like the hibiscus, pawpaw, and *Vernonia*. Compound leaves are found in *Cassia*, silk-cotton, and the rose.

The way in which the portions of leaves are arranged on the leaf-stalk gives rise to two main forms. When the leaf divisions form a radiating series like the fingers of a hand, we refer to the leaf as *palmate*. Among simple leaves examples of such palmate types are cassava (Fig. 26.3) or manioc, and the pawpaw. In compound leaves examples of palmate types are the silk-cotton and *Oxalis*.

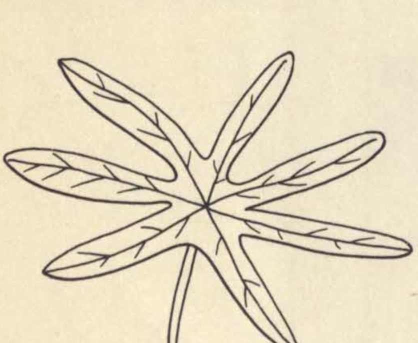


Fig. 26.3. Leaf of cassava (palmate)

When the leaf divisions are in two series on each side of the common axis, the leaf is referred to as *pinnate*. In simple leaves the central axis is the midrib, as in *Lactuca taraxacifolia* (Fig. 26.4). In compound leaves the axis is an extension of the petiole, and examples are the nim tree and *Cassia* (Fig. 26.5).

Internal Structure of a Leaf

When we examine under the microscope a transverse section or cross-section cut from a foliage leaf (Fig. 26.6) we find that the leaf is made

Fig. 26.4. Leaf of *Lactuca taraxacifolia* (pinnate)

Fig. 26.5. Leaf of *Cassia* (compound)

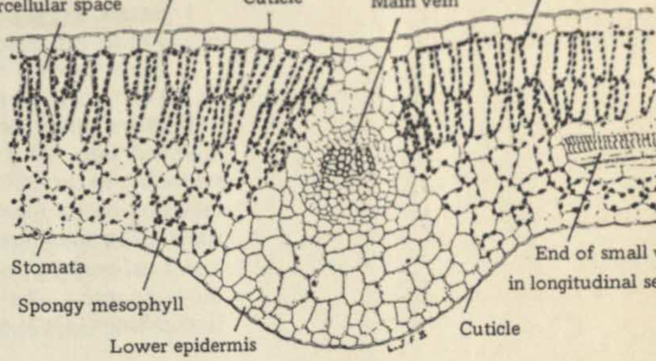


Fig. 26.6. Transverse section of leaf

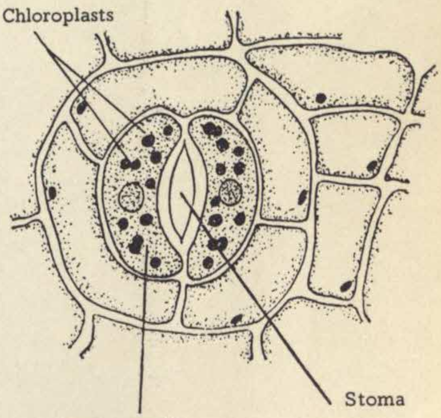
up of a number of different tissues. The upper and lower surfaces each consist of a single layer of brick-shaped cells forming the upper and lower *epidermis*. These cells have no green chloroplasts. In some plants, such as the balsam or plants from shady places, there may be minute pores called *stomata* among the cells of the upper epidermis, but in most leaves the stomata are only found among the cells of the lower epidermis. The exposed surfaces of the cells of the upper and lower epidermis are covered with *cuticle* which prevents evaporation of water from their cells. In some plants, like the *Allamanda*, the epidermis bears hairs which also help to reduce loss of water.

The tissues of the leaf-blade between the two epidermal layers are called the *mesophyll*, and have small green chloroplasts which contain chlorophyll. The latter is essential in photosynthesis. There are two types of mesophyll cells, the upper mesophyll called the *palisade tissue*, and the lower mesophyll called the *spongy tissue*. The palisade tissue usually consists of two layers of long cells closely arranged at right-angles to the surface of the leaf. They often contain more chlorophyll than the lower spongy tissue. The latter is made up of cells of irregular shapes with large air spaces between them.

In the mesophyll can be found a section of the midrib and the veins, which contain, among other cells, the vascular bundles which carry solutions to and from the leaf.

As mentioned above, the lower epidermis is often well supplied with stomata. A stoma is in fact a hole or pore around which are two bean-shaped cells called *guard-cells* (Fig. 26.7). These are the only cells in the epidermis with chloroplasts and they control the closing and opening of the stomatal pores in response to environmental changes.

Fig. 26.7. Stoma



Leaf-fall. As the leaves grow old they change colour and eventually drop off. Before a leaf falls, a thin layer of tissue, called the *absciss layer*, grows across the base of the petiole and forms a line of weakness; the leaf, cut off from its supplies of water and mineral salts, is soon blown off. As the leaf drops it leaves a mark on the stem known as the *leaf-scar* and made of cork tissue which formed beneath the absciss layer.

Modified Leaves

There are various structures on certain plants which are modifications of the ordinary foliage leaf, as described below.

1. Scales. We have already mentioned in Chapter 24 the brown remains of leaves, called scales, which are found on bulbs and tubers.

2. Scale-leaves. These are found in buds (Fig. 23.5) and bulbs (Fig. 24.13) as already described.

3. Hairs and Spines. In a few plants the leaves are either absent or modified into hairs or spines which are unable to carry on photosynthesis; in these plants the work of the leaf in manufacturing food is taken on by the stem, as in cactus or *Euphorbia* (Fig. 24.9) or by the roots, as in some orchids.

4. Leaf-tendrils. In plants like the *Gloriosa* lily, the tip of the leaf is modified into a *tendril* which is a long, thin structure used by the plant in climbing (Fig. 26.8).

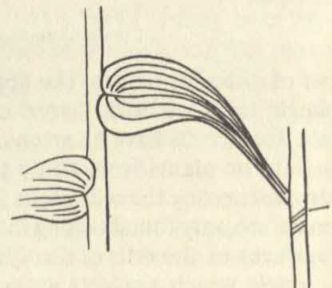


Fig. 26.8. Leaf tendril of *Gloriosa* lily

5. Food-storage Organs. We have already mentioned *Bryophyllum* (Fig. 24.15) where the leaf is thick with stored water and food substances.

SUGGESTED PRACTICAL WORK

1. Collect, from the school compound, palmate and pinnate types of simple and compound leaves and draw them.

Carefully draw a single leaf of the hibiscus, labelling all its parts.

2. With the aid of a hand-lens, examine the pores (stomata) in a number of leaves. The teacher will provide a demonstration of the shape and structure of stomata from a strip of leaf epidermis mounted under the microscope.

It is quite an easy matter to learn the technique for obtaining epidermal strips from leaves. First of all select a fairly thick leaf—for example, from the harmattan lily or the spider lily. Next take a pair of fine, narrow forceps and 'nip' a small piece of the leaf surface. With a quick hand movement strip off a portion of the leaf epidermis (a small piece is all that is needed), and mount it in a tiny drop of water on a glass slide. Apply a cover-slip and examine the slide under the microscope.

By using this epidermal strip technique it is possible to compare the number of stomata on the upper and lower epidermis of a variety of leaves.

3. Your teacher will show you under the microscope a stained section of the leaf of hibiscus, *Clerodendron*, *Ixora*, or other suitable leaf. Do not try to draw it, but you should be able to recognize the various tissues.

4. Draw the leaves of *Gloriosa* lily and *Bryophyllum*.

CHAPTER TWENTY-SEVEN

Sexual Reproduction in Flowering Plants—The Flower, Pollination, and Fertilization

WE have already discussed in Chapter 24 the various devices used by underground stems in vegetative reproduction. Those methods or modifications for this mode of reproduction are in fact exceptional and are found to be limited to special plants and under special conditions. The normal method of reproduction in the flowering plants is that of sexual reproduction by means of flowers and seeds.

Structure of Flowers

The flower is considered a shoot whose parts are modified for the purpose of producing seeds. As a shoot it has leaves called *floral leaves*, which are modified into four different structures known as *sepals*, *petals*, *stamens*, and *carpels*. These are closely arranged in rings around a swollen end (the *receptacle*) of the supporting stem (the *stalk*). A simple flower of a common plant like the flamboyant (*Delonix* or *Poinciana regia*) (Fig. 27.1), which is widely distributed in the tropics, will serve to show us clearly the different parts of a flower and their respective functions.

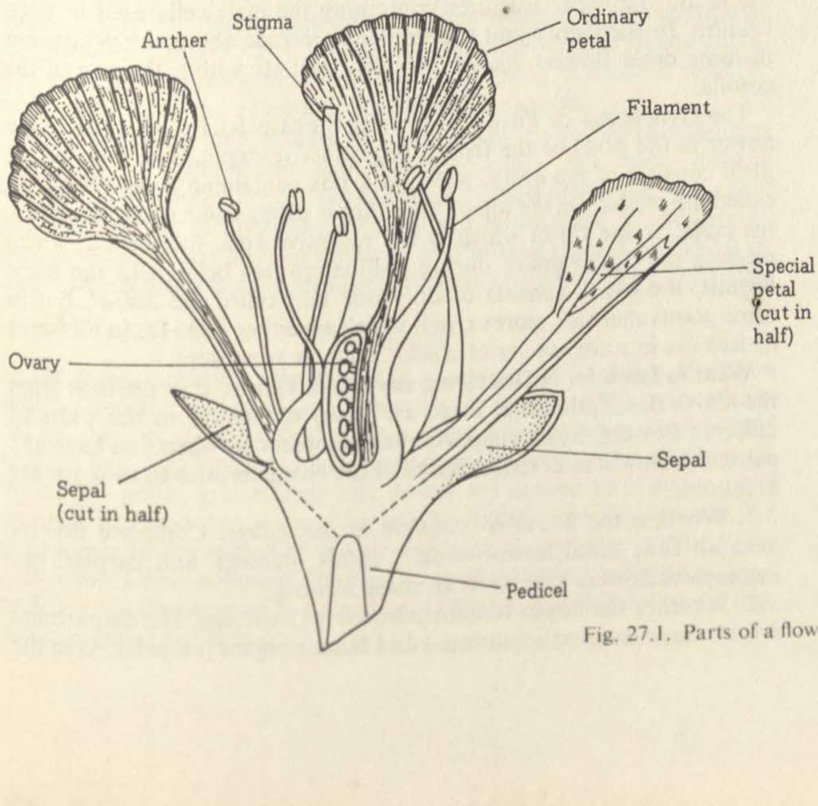


Fig. 27.1. Parts of a flower (flamboyant)

The Calyx (comprising the sepals). The outer and lowest group of the floral leaves is made up of the sepals which together form the calyx. In the flamboyant there are five of these, separated from each other and coloured green outside and red inside.

The main function of the calyx is to protect the young flower when it is in the bud. The calyx is usually green, has veins, and looks like a reduced leaf. In some plants the sepals forming the calyx are joined together into a tube, as in the hibiscus flower. Below the calyx in the hibiscus, as in certain other plants, are more small leaf-like structures which together form the *epicalyx*.

The Corolla (comprising the petals). Just above or inside the calyx is another group of five brightly coloured *petals* which together form the *corolla*. One of them is differently coloured and stands upright. The function of the showy petals is to attract the attention of insects, whose visit to the flower results in pollination. The corolla often produces a perfume for the same purpose. At the base of the petal there may be a *nectary* containing a sweet juice on which the visiting insect feeds. In the flamboyant the petals are free, but in some other flowers, like the *Allamanda*, they are joined together in a corolla tube. The term *perianth* is used for both the calyx and the corolla, and it is often used in describing the flowers of monocotyledons where the petals and sepals are so alike as not to be easily distinguished.

The Androecium (comprising the stamens). Inside the corolla comes a number of slender structures, the *stamens*, which together form the *androecium*, or the male organs. Each stamen consists of a stalk, the *filament* bearing at its apex a yellow bi-lobed structure, the *anther*. When an anther is cut across it is seen that each lobe has two sacs, the *pollen sacs*, which are filled with a dustlike substance, the *pollen grains*. These are the male structures containing the male cells used in fertilization. In the flamboyant the stamens protrude above the petals, but in some other flowers, like *Allamanda*, they are within the cup of the corolla.

The Gynoecium or Pistil (comprising the carpels). In the centre of the flower is the *pistil* or the female reproductive organ. The base of the pistil consists of the *ovary*, which is a box containing rounded bodies called the *ovules*. On the top of the ovary is a long and narrow structure, the *style*, at the tip of which is the receptive area, the *stigma*, which receives the pollen grains during pollination (see below). In the flamboyant, the ovary consists of only one unit called the *carpel*, but in some plants there are more carpels which are either fused (as in hibiscus) or free (as in most species of *Anona*, such as sweet sop).

What to Look for in Describing any Given Flower. It is obvious from the above description that there are many differences in the parts of different flowers. So it is important to be observant when you have any particular flower to describe. Some of the characteristics to look for are as follows:

1. Whether the flower is *complete* or *incomplete*. Complete flowers have all four floral leaves—sepals, petals, stamens, and carpels, but incomplete flowers have some of these missing.

2. Whether the flower is *hermaphrodite* or *unisexual*. Hermaphrodite flowers have both male (stamens) and female organs (carpels), as in the

flamboyant, but unisexual flowers have either only male or only female organs, as in the pawpaw.

3. Whether the flower is *regular* or *irregular*. Regular flowers are symmetrical—that is, when any such flower is divided into two halves in any plane the two parts are similar, as in the moon-flower or morning glory (*Ipomoea*). Irregular flowers can be divided into two equal halves in one plane only, as in the flamboyant or *Crotalaria* (Fig. 27.4). It is believed that irregular flowers are more highly developed than regular ones.

4. The number of members of each group of floral leaves, that is, the number of sepals, petals, stamens, and carpels. If the number of any group is more than 20 it is not necessary to count them all, but only to state simply that it is indefinite. Very reduced stamens are called *staminodes*. Smaller numbers of stamens are associated with flowers of advanced species.

5. Whether the members of each group are fused together. Fused parts are believed to be more advanced than free ones. We have already mentioned flowers with fused sepals and petals. The hibiscus is an example of a flower with fused stamens. When the carpels are fused the number can be determined only after cutting a transverse section of the ovary.

6. Whether or not the members of each group are attached to the members of another group. For example, are the petals attached to the sepals or to the stamens in such a way that one of them cannot be removed without removing the other?

7. Whether the ovary is *superior* or *inferior*. That is, whether the receptacle is conical, with the ovary on top of it (superior), or cup-shaped with the ovary inside it (inferior).

8. Whether there is a nectary at the base of the petals.

9. Whether the stamens are above or below the level of the stigma.

It is also essential to look for any special modifications of the parts; for example, the enlargement and bright colouring of a single sepal of certain flowers such as found in species of *Mussaenda*.

Try to describe some flowers as suggested at the end of this chapter.

Flowers of Dicotyledons and Monocotyledons. We have already mentioned that in monocotyledons the sepals and petals are very alike, unlike those of dicotyledons. Again, the floral parts of flowers of monocotyledons are often in threes or multiples of three, while those of dicotyledons are generally arranged in fours or fives or their multiples.

Pollination

The main purpose of the flower is to ensure the transfer of pollen grains from the anther of one flower to the stigma of the same or another flower of the same kind. This process is known as *pollination* and it is the first step leading to fertilization and the formation of the seed. When the pollen grains from one flower are carried to the stigma of another, it is said that *cross-pollination* has taken place. If, however, the pollen gets to the stigma of the same flower, the process is called *self-pollination*. Cross-pollination is often more effective than self-pollination, and the construction of certain flowers prevents self-fertilization but achieves cross-fertilization.

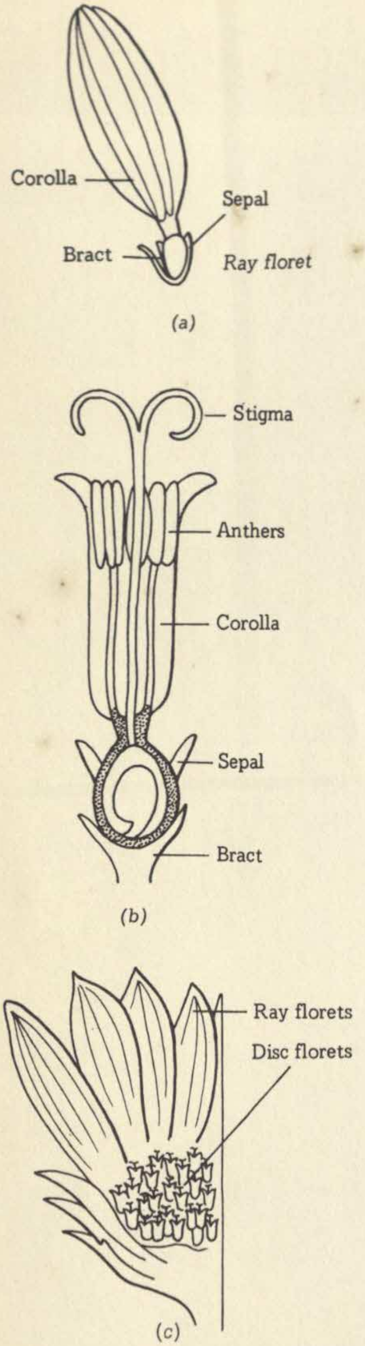


Fig. 27.2. Sunflower: (*a*) ray floret; (*b*) disc floret; (*c*) part of a vertical section through a capitulum

The way in which the parts of any flower are arranged suits the method by which the process of pollination is carried out in that particular flower. The two principal agents by which pollination is brought about in many flowers are insects and the wind.

Pollination in Some Insect-pollinated Flowers

Insects play a very important role in the pollination of plants. Bees, butterflies, and moths are the principal insects which carry out pollination, and in nearly all cases this is due to the fact that such insects feed on nectar and pollen. For this reason, the mouth-parts of these insects are adapted for sucking nectar (see Chapter 8). Bees have their legs adapted for carrying pollen grains and for brushing them off their bodies, as mentioned in Chapter 10.

Flowers that are pollinated by insects often have brightly coloured petals or sepals, nectar, or an attractive scent. The stigmas and pollen are also sticky. The flower itself is often large and the parts are shaped to suit the behaviour of the insect when feeding. The mechanism of insect pollination will be illustrated by the sunflower, *Thunbergia*, flamboyant, and the sweet-pea bush (*Crotalaria*).

1. The Sunflower (*Helianthus annus*). The sunflower (Fig. 27.2) is a compound flower because it consists of a great number of small flowers (called *florets*) crowded together into a head or *capitulum* and surrounded by a number of overlapping sepal-like bracts. The florets have no sepals but bear two small scales. There are two types of florets. Those nearer the outer part of the head (called *ray florets*) have long, brightly coloured corollas shaped like straps; their ovaries do not contain ovules. The other type of florets (the *disc florets*) occupy the inner part of the head and have tube-shaped corollas. The disc florets are specially adapted for pollination. Their corolla is regular and tubular, and consists of five petals.

The stamens are five in number and joined to the corolla. They are also joined together by their anthers. The ovary consists of two fused carpels containing only one ovule. On the ovary stands the long style with two stigmas.

Pollination mechanism in the sunflower is influenced by the fact that it is *protandrous*, that is, the stamens ripen before the stigmas. As the stamens ripen the anthers are split along their inner sides, so that the pollen is shed into the tube formed by the anthers, which are joined together. At this time the short style below the pollen tube and the receptive surfaces of the two stigmas are pressed together so that pollen cannot reach them. Later, the style elongates, pushing the pollen out of the anther tube, and the stigmas open out to expose the stigmatic surfaces. The youngest of the disc florets are in the very centre of the capitulum with the older ones around them. Thus by the time the central young ones have reached the stage where only the pollen grains are released, the older, outer ones have already got their stigmas above the stamens and their stigmatic surfaces are exposed.

The bee which causes pollination in the sunflower first settles in the centre of the capitulum. It receives pollen all over its legs and undersurface as it walks outwards. When it reaches the older flowers the pollen grains from its body are spread on the exposed stigmatic sur-

faces, and pollination is effected. Because the pollen grains appear before the stigmas it appears impossible to have self-fertilization; but if cross-fertilization as described fails, the stigmas curl round to pick up their own pollen grains and thus secure self-pollination.

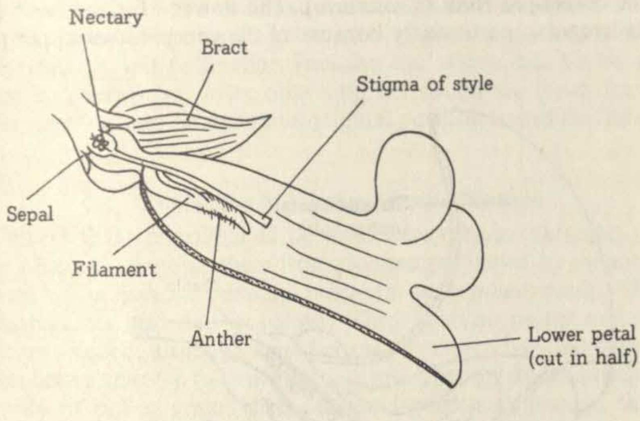


Fig. 27.3. *Thunbergia* flower

2. Thunbergia (Fig. 27.3). In the first place the flower of this plant has an attractive colour. It is also irregular, with one of the petals modified into a landing platform which projects forward on the lower part of the corolla cup. Inside this platform are well-defined lines. As the carpenter bee, which often brings about pollination in this flower, lands on the platform it is guided by these lines towards the nectary at the base of the corolla and ovary. Soon the back of the insect comes into contact with the wet stigma of the flower. In this way any pollen dropped on the back of the insect from a visit to a previous *Thunbergia* is deposited on the stigma, and pollination is effected. At the same time the head of the insect brushes aside the broad filaments to create an open space for itself; but the head cannot go any farther because of the narrowing of corolla. Here the bee extends its proboscis and inserts it through the small aperture into the nectary to suck the nectar. As the head is moved during the sucking of the nectar, the anthers of the flower are shaken and so pollen drops on to the back of the insect. After sucking the nectar, the bee flies to another flower where the process is repeated.

3. Flamboyant (*Delonix* or *Poinciana regia*). The flower (Fig. 27.1) of this tree has been sufficiently described earlier. Large butterflies with long probosces are attracted from long distances by the bright red colour of the flowers. As the insect approaches the flowers it is often rather dazzled by the mass of brightly coloured flowers. In this confusion the attention of the insect is caught by the single petal (called the *labellum*) which is differently coloured and stands upright. In trying to reach this petal the insect lands on the stigma which projects in front of it above the stamens. The pollen of the last flower which was visited by the butterfly may still be on its head and is dropped on the stigma, so cross-pollination takes place. As the insect attempts to suck nectar

from the nectary situated at the base of the yellow petal, pollen from the stamens of the flower are shed on its body. The butterfly leaves this flower and moves to another, on whose stigma it may leave some of the collected pollen. After pollination the nectar is covered by the petal near it and this prevents further visits by butterflies.

4. The Sweet-pea Bush (*Crotalaria*). The flower of *Crotalaria* (Fig. 27.4) is irregular, particularly because of the conspicuous upper petal

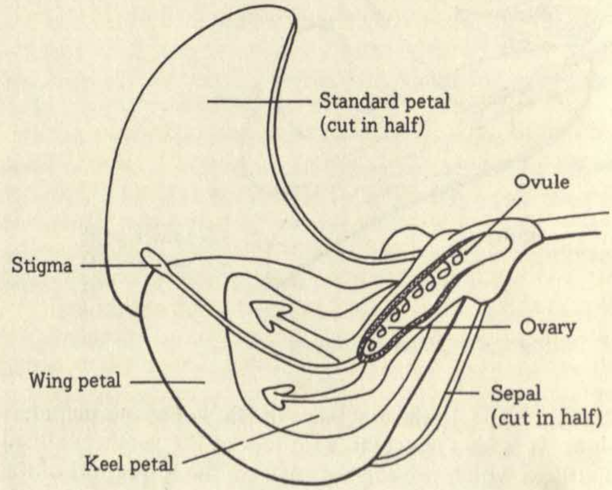


Fig. 27.4. *Crotalaria* flower

known as the *standard*. There are five green sepals (the two upper ones being large) which are joined together to form the calyx. The corolla consists of five petals, of which the two front ones are joined to form a boat-shaped structure, called the *keel*; the side ones are called *wings*; while the posterior one, which is the largest and stands up or curls back, is called the *standard*. The keel is so shaped that the lower part forms a tube with a narrow opening. Inside the standard are lines which serve as guides to the nectary. Within the keel are ten stamens joined in the middle by filaments, while the free ends bend upwards. Inside this filament tube nectar is secreted from the nectary. The pistil comprises an ovary of a single carpel on which is a long style bent upwards roughly at right-angles and bearing the hairy stigma.

Pollination in *Crotalaria* is carried out by the bee, whose long proboscis can reach the nectar. The conspicuous standard attracts the insect, which on arrival is guided by the lines inside this petal towards the nectary. The bee actually lands on the *wings*, which are depressed, thus depressing the keel. At this time the five inner stamens have already shed their pollen into the tube formed by the upper end of the keel, and are found lying in the lower part of the keel. The filaments of the outer stamens, on the other hand, have then just reached their full growth, and are much longer and have swollen club-shaped ends. They lie above the inner withered stamens and tightly close the base of the pollen-containing tube. A slight downwards pressure on the keel by the bee

forces the thickened ends of the fine outer filaments further into the tube, and squeezes a ribbon of pollen through the narrow opening on to the under-surface of the bee. As the pressure increases the stigma protrudes above the opening. When the bee tries to reach the nectar the stigma rubs against it and receives pollen from flowers previously visited. In this way cross-pollination takes place. Although some pollen from the same flower could get on the stigma by chance, this would rarely lead to self-pollination because the stigma has to be rubbed before it is receptive. After obtaining the nectar the insect leaves the flower, and the keel returns to its original position to enclose the stigma.

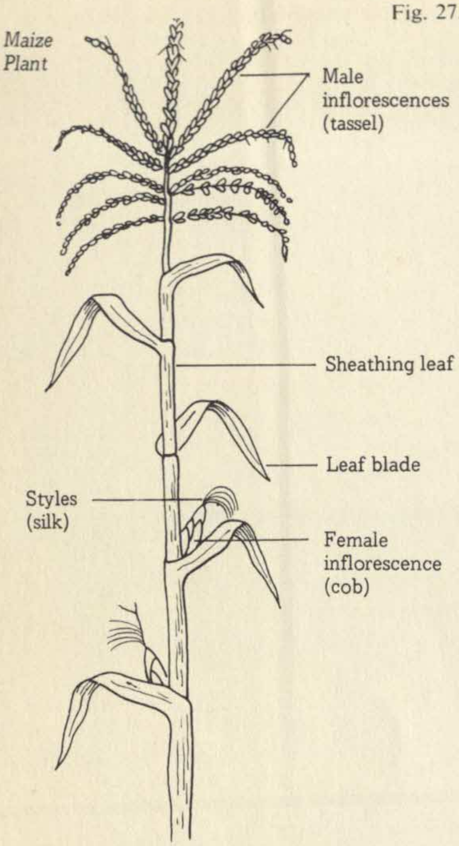
Pollination in Wind-pollinated Flowers

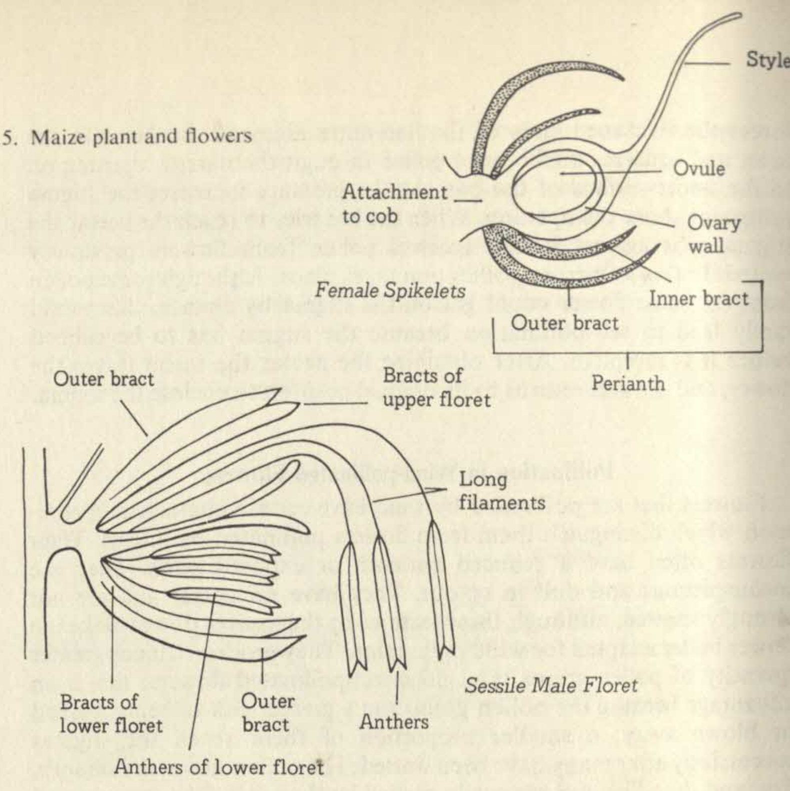
Flowers that are pollinated by wind have certain characters in common which distinguish them from flowers pollinated by insects. Their flowers often have a reduced perianth or exposed parts. They are inconspicuous and dull in colour. They have no nectar and are not strongly scented, although these features by themselves do not make the flower better adapted for wind pollination. They produce a much greater quantity of pollen grains than do insect-pollinated flowers; this is an advantage because the pollen grains run a greater risk of being washed or blown away; a smaller proportion of them reach the stigmas successfully after many have been wasted. The pollen grains are smooth, dry, and dust-like and are easily carried by the wind. The stamens and stigmas are pendulous and exposed to the air, particularly in plants which shed their leaves at the time of flowering, as in *Adansonia*, the baobab, and *Ceiba*. The anthers are borne on long filaments which swing in the wind, as in the grasses, while the stigmas are often hairy or sticky and may be branched (as in the pawpaw and castor–oil) or are very long with a large surface area for catching pollen. They protrude out of the flower (as in maize) and are feathery (as in the grasses generally). These devices help not only the discharge of the pollen but also its ready collection by the stigmas.

The flowers are not usually hermaphrodite but have separate sexes, that is, each flower is either male or female (unisexual). A description of pollination in the maize will serve as a good example.

Pollination in Maize. The maize plant has a wind-pollinated flower (Fig. 27.5). A large number of male flowers are borne separately in a much-branched inflorescence at the top of the plant, while female flowers, collected into maize cobs, are found in the axil of each leaf, lower down the stem. A male flower has a number of scaly bracts enclosing three stamens with long filaments. The anthers thus protrude and are borne on the very narrow tip of the filaments, so that with their light weight they are easily moved by the wind. When a maize cob is cut lengthwise, the female flowers are found to form a compact inflorescence. Each flower is stalkless and is contained in the axil of a scaly bract. The ovary has only one ovule, and above it is an extremely long style with a hairy stigma. The inflorescence is covered by large overlapping sheathing bracts to form the cob. At the top of this there projects and hangs freely in the air a tuft of fine, long, silky threads formed by styles of all the female flowers. Neither the male nor female flowers

Fig. 27.5. Maize plant and flowers





have perianth leaves (sepals and petals) and they are not scented.

The maize plant is protandrous, that is, the male flowers ripen before the female ones. The pollen is shed before the female flowers of the same plant are ready for pollination. This prevents self-pollination. When the anthers of one plant burst, the pollen grains are shed like a cloud of dust, which floats in the air close to the plant. Many of the pollen grains are blown away and wasted, but some of them are caught by the protruding stigmas on the same or other plants and pollination is thus achieved.

Fertilization

Fertilization may be defined as the actual union of two sex-cells, or gametes. In the flowering plants this takes place inside the ovule after several changes following pollination. The events which take place between pollination and fertilization are as follows (see Fig. 27.6).

When the right kind of pollen grain reaches a receptive stigma, it proceeds to germinate. The outer covering wall of the pollen breaks and the contents grow out into a long thin-walled structure called the *pollen tube*. The pollen tube enters the tissue of the style and continues to grow until it reaches the ovary. Before it enters the ovary two *male gametes* or cells are formed from a single nucleus in the pollen tube. When the pollen tube reaches an ovule its tip enters the *micropyle*, which is a hole at one end of the tissues which cover the ovule. Here the tip of the pollen tube bursts to release the two male gametes into the embryo-sac.

At this time the embryo is ready for fertilization and consists of an oval-shaped body with a number of nuclei, the most important of which

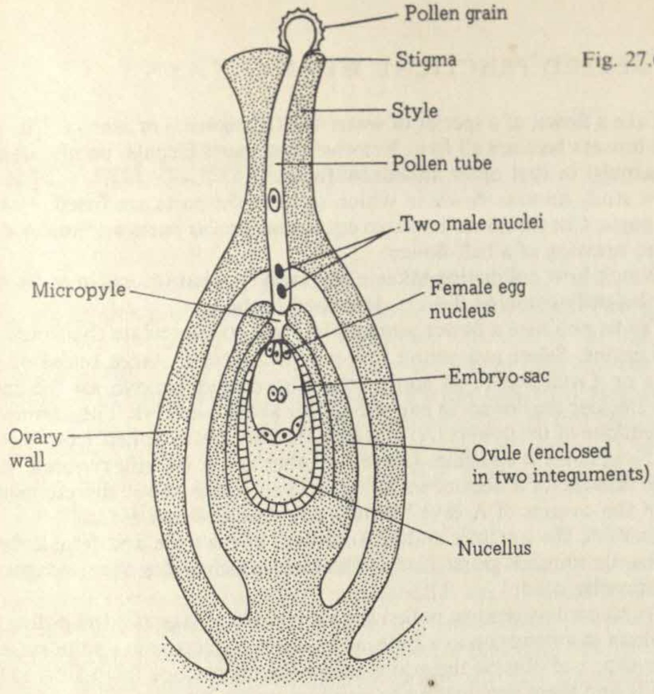


Fig. 27.6. Vertical section through a carpel showing fertilization

are two nuclei, one lying near the micropyle end (the *egg-nucleus*) and the other in the centre. One of the two male nuclei set free by the pollen tube unites with the *egg-nucleus* and forms the zygote, which will grow into the *embryo* of the seed. The second male nucleus fuses with the central nucleus of the ovule. In some plants this develops into the *endosperm* which contains the food reserve for the embryo.

Development of the Fruit

As the fertilized ovule grows into the *seed*, the whole ovary becomes the *fruit* while the ovary wall becomes the fruit wall or pericarp. Fertilization stimulates the tissues outside the embryo-sac to grow actively, especially those of the endosperm which grows around the embryo. These tissues are as follows: just outside the embryo is the *endosperm*, and outside this the *nucellus*. Then come the two layers of tissues called the *integuments* which leave the gap or hole called the *micropyle*. The integuments grow to close the micropyle and become greatly thickened to form the *seed coats* or *testa*.

The nucellus generally disappears before the seed is fully formed, while the endosperm often stores food which is used by the seed during germination. But in some plants such as the flamboyant and other legumes, the endosperm is entirely used up by the embryo before the seed is mature. In such cases the food is stored in the seed-leaves, or *cotyledons*, of the embryo. The embryo also begins to develop the *radicle* (future root) and the *plumule* (future shoot). The wall of the ovary also grows rapidly and keeps pace with growth of the seed, and the whole structure becomes the fruit.

By this time the style has withered away, and so have the stamens and the perianth.

SUGGESTED PRACTICAL WORK

1. Take a flower of a species of water-lily (*Nymphaea*) or *Anona.* The parts of the flowers here are all free. Remove these parts (sepals, petals, stamens, and carpels) in that order and draw them.

Now study another flower in which some of the parts are fused. Note the fused parts. Cut the flower into two equal and similar parts and make a well-labelled drawing of a half-flower.

2. Watch how pollination takes place (and by what insect) in at least one of the brightly coloured flowers described in the text.

3. Try to pollinate a flower yourself in order to appreciate the function of pollen grains. Select two young flowers (preferably as large buds) of flamboyant or *Crotalaria* or of some other flower and remove all the anthers intact. Enclose the flowers in paper bags for about two days. Then remove the bag from one of the flowers (A) and dust its stigma with pollen from an older flower, and cover it up again. Leave the other flower (B) still covered. Watch the two flowers for a week or so. What do you notice about the comparative sizes of the ovaries of A & B? Which one develops into a fruit?

4. Examine the structure and arrangement of the male and female flowers of maize or another grass. List all features which make them adapted for pollination by wind.

5. Try to germinate some pollen grains yourself; shake out the pollen from the anthers of a flower on to a slide, add a drop of dilute sugar solution, apply a cover-slip, and observe the grains under the microscope from time to time. You will find them germinating to produce pollen tubes.

Try two other dilutions of the sugar solution. Has the dilution any effects on the rate of growth of the pollen tubes?

CHAPTER TWENTY-EIGHT

Fruit and Seed Dispersal

THE fruit of a flowering plant is the fertilized and ripened ovary. The fruit of the great majority of plants contains seed. The popular view is that a fruit is necessarily edible, but this is wrong, since according to the above definition there are fruits of many weeds which are not used as food. Also, not all that we eat and call 'fruit' is developed from a ripened ovary; in other words, some 'fruits' are not fruits in the true botanical sense. For example, the juicy part of cashew (Fig. 28.1) which we eat is not a developed ovary but a receptacle. The proper fruit here is really the hard kidney-shaped nut.

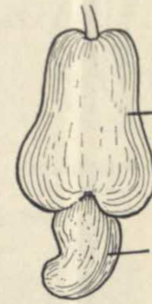


Fig. 28.1. Cashew

Before proceeding to discuss the types of fruits, it is important to stress how a fruit differs from a seed. We have already mentioned that the seeds are inside the fruit. But some small fruits look like seeds, while some seeds when outside the fruit look like small fruits. A reliable way of distinguishing between a fruit and a seed is that the fruit always has two scars which are the *scar of attachment* by which it was attached to the stem, and the *scar of the style* by which the style and stigma were attached to the fruit. The seed, on the other hand, has only one scar, the *hilum* (see Chapter 29), by which it was attached inside the fruit. It is a common mistake to refer to a maize grain (Fig. 28.3), for example, as a seed; it is in fact a fruit in which the thin ovary wall is closely attached to the single seed inside it. The sunflower and many cereals and grasses have similar fruits which are wrongly called seeds.

Types of Fruits

Fruits may be divided into two main groups, namely:

(1) *simple* fruits, that is, fruits formed from a single flower, such as the bean pod or tomato, and

(2) *collective* fruits (Fig. 28.2) which are fruits formed from many flowers or an inflorescence, such as species of *Lantana*, the mulberry, *Anona*, and the pineapple. These are often called 'false fruits' because they are not developed from the ovary alone, but may involve other parts of the plant.

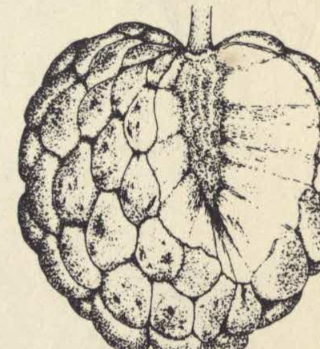


Fig. 28.2. A succulent collective fruit

Whether simple or collective, fruits may be *dry* or *fleshy*.

Dry Fruits. Some dry fruits do not discharge their seeds and are said to be *indehiscent*.

The small fruits which are often mistaken for seeds, such as the maize grain, sunflower, *Tridax*, and the grasses mentioned above, are dry fruits which do not open to discharge their seeds. These are called *achenes* (Fig. 28.3) but large indehiscent fruits, like the cashew-nut and *Coralita*, which are made up of two or more carpels which may be called *nuts*.

Other dry fruits which open to let out their seeds are said to be *dehiscent*. If the fruit was formed from one carpel it is either a *legume*

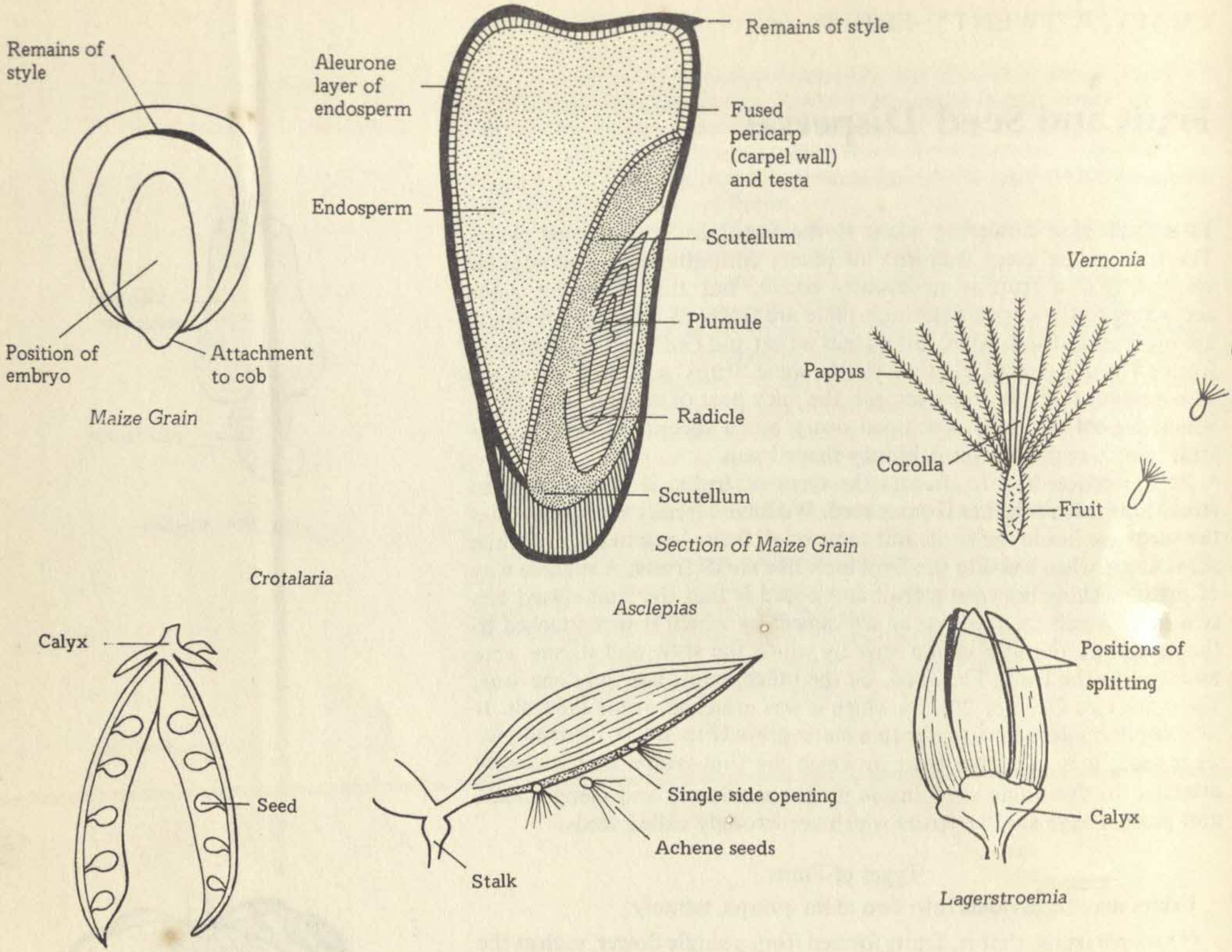


Fig. 28.3. Dry fruits

or a *follicle*. If formed from many carpels it is a *capsule*.

Legumes. The legumes are very common and are characteristic of the large family called *Leguminosae*. The legume splits along two sides (while the follicle as stated below splits along only one side). Examples of legumes include Pride of Barbados, *Crotalaria* (Fig. 28.3), beans, and peas.

Follicles. Follicles are not as common as legumes, to which they are sometimes similar in shape, and they split on one side only. Examples include *Sterculia foetida*, frangipani, and *Asclepias* (Fig. 28.3).

Capsules. Capsules are rather common. Examples include cotton, mahogany (Fig. 28.4). and queen of flowers (*Lagerstroemia*) (Fig. 28.3). In certain fruits the carpels merely separate into fruitlets, as in castor-oil (Fig. 28.4). These are called splitting fruits.

Fleshy Fruits. Fleshy fruits are divided into groups depending on the nature of the fruit wall. For this purpose we should mention here that the wall of a fruit (the *pericarp*) has three parts. These are the outer

epicarp, the middle *mesocarp*, and the inner *endocarp*. The main groups of fleshy fruits are the *berries*, the *drupes*, and the *pomes*.

The Berry. In the berry the fruit wall is fleshy throughout. Examples include the tomato, pepper, and the guava. The orange (Fig. 28.5) is a berry in which the ovary wall has a glandular epicarp, and the endocarp produces outgrowths to form the juicy pulp.

The Drupe. In the drupe the endocarp of the fruit wall is hard and forms a stone. Examples include the mango (Fig. 28.5), Indian almond (*Terminalia*) (Fig. 28.6), the coconut (Fig. 28.5), and the oil-palm fruit. In some of these, such as the mango, the mesocarp is juicy, while in others, like the coconut and the Indian almond, the mesocarp is fibrous and this makes the fruit light and buoyant.

The Pome. This consists of a juicy, swollen receptacle surrounding the pericarp, which is itself rather stiff and not edible. A pome is described as a false fruit, since the true fruit formed from the ovary is hidden inside the fleshy receptacle. Good examples of pomes occur in the fruits of *Malus* (apple) and *Pyrus* (pear), best known in temperate climates.

Dispersal of Seeds and Fruits

So that the large number of seeds produced by a plant may be easily dispersed, various devices have been evolved which favour the agents used for dispersal. This is necessary to prevent over-crowding of the seedlings which would otherwise occur if all the seeds germinated

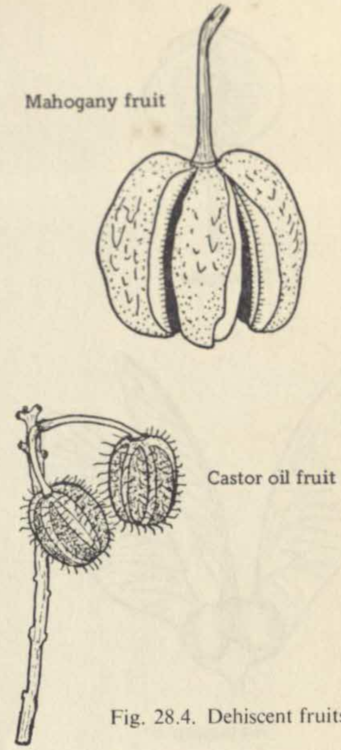
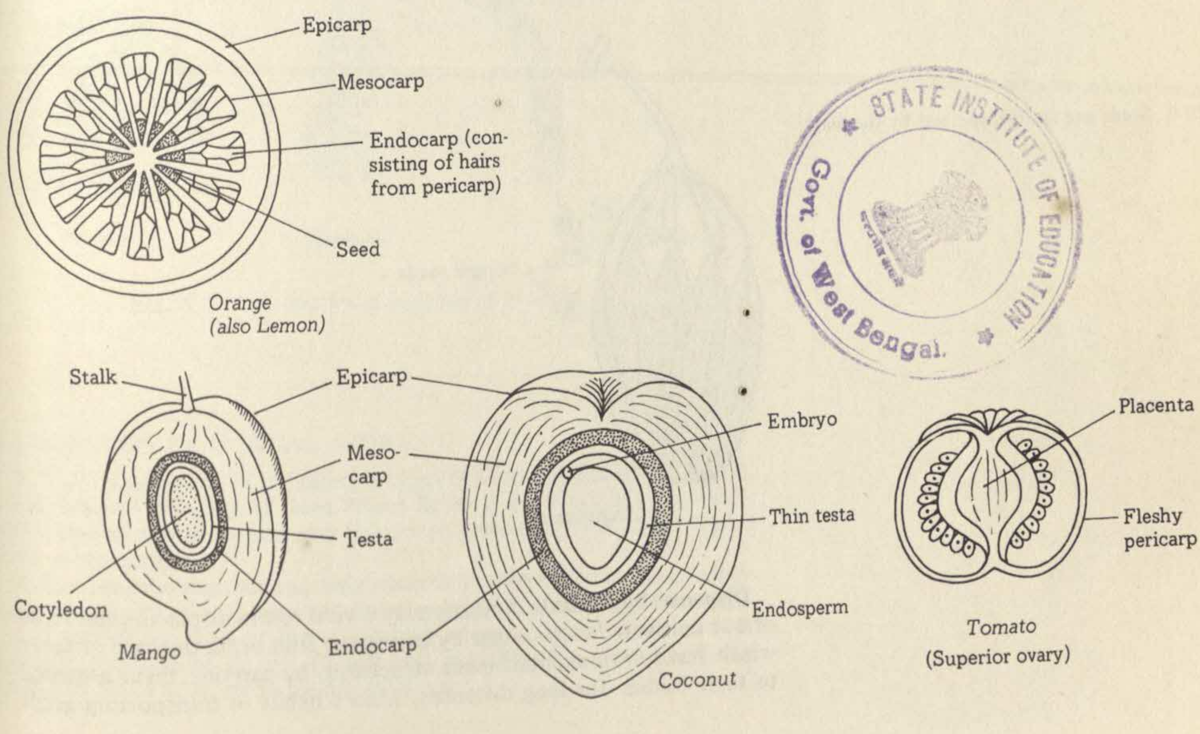


Fig. 28.4. Dehiscent fruits

Fig. 28.5. Fleshy fruits



beneath the mother plant. The common agents by which dispersal of seeds and fruits is carried out are explosive mechanisms in the fruit itself, wind, animals, and water.

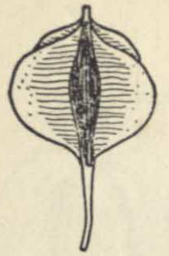
Self-dispersal. The seeds of certain plants are shot some distance away from the fruits by mechanisms in the fruit itself, which cause the pericarp to rupture violently. Common examples include the balsam, the castor-oil plant (Fig. 28.4), and para-rubber. In the balsam the valves of the pericarp suddenly roll up when the fruit is lightly touched by any object.

Wind Dispersal. Plants which disperse their seeds with the aid of the wind often produce seeds in great abundance so that a few at least may reach a suitable spot for germination, even if the majority are left in situations that are unfavourable. The wind is able to disperse the seeds over fairly long distances, and it is an advantage if the seeds are small and light, as in the orchids and in *Begonia.*

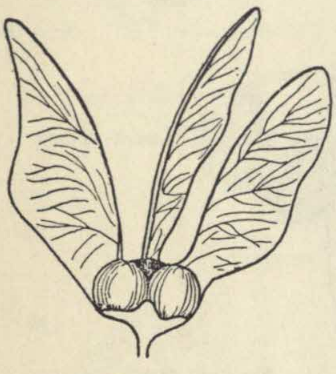
In many fruits and seeds special outgrowths are developed which help dispersal by the wind. Examples include *Combretum*, *Pterocarpus*, and *Acridocarpus* (Fig. 28.6).

In some plants, especially those belonging to the Compositae, such as *Vernonia cinerea* (the blue fleabane), or *Tridax*, the calyx is in the form of a hairy pappus or parachute. This enables the fruits to be suspended in the wind during dispersal. Cotton is a good example of a plant where hairs or plumes are used for dispersal.

Finally, the seeds themselves may be winged, as in *Tecoma* and *Aristolochia* (Fig. 28.6).



Terminalia



Acridocarpus

Aristolochia

Fig. 28.6. Seeds and fruits dispersed by the wind

Dispersal by Animals. Animals play a vital role in dispersing the seeds of our cultivated crops either by eating the fruit or, in the case of seeds which have various attachment structures, by carrying them attached to their bodies for long distances. Man's habits of transporting seeds

on him as well as man's means of modern communication contribute a lot towards the dispersal of seeds and fruits. In some cases the whole fruit is eaten and the seeds pass through the alimentary canal. When the faeces are deposited the seeds are still able to germinate because they have a slimy covering which protects them during their passage through the alimentary tract. Birds often eat guava, bird-pepper, and tomatoes and disperse their seeds in this way. This is said to be an *internal* method of dispersal. Generally, animals disperse seeds by eating the fruits and leaving the seeds about, as with the mango and oranges.

Another important way in which animals disperse fruits and seeds is, as already mentioned, by means of the hooks or sticky hairs developed on the seed's surface. These adhere or cling to the animal's pelt until they are brushed off elsewhere. This is an *external* method of dispersal. The fruits of different types of burs, such as *Acanthospermum, Wissadula, Urena* (Fig. 28.7), and *Bidens*, have backwardly directed hooks for the purpose, and the fruits of sweetheart (*Desmodium*) (Fig. 28.7) have sticky hairs for this type of dispersal.

Water Dispersal. Water can carry fruits and seeds long distances, but only those with flotation devices and near a river or the sea-shore are successfully dispersed in this way. The flotation device often consists of an impervious covering of fibrous or corky material as in the coconut. Common examples of fruits dispersed in this way are the coconut (Fig. 28.4), the water-lily, and the mangrove.

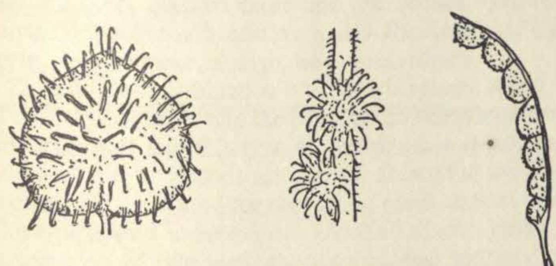


Fig. 28.7. Seeds and fruits dispersed by animals

SUGGESTED PRACTICAL WORK

1. Make a collection of the different types of fruits mentioned in the text. Make labelled drawings of them. Some fleshy fruits which are not easily obtainable all the year round may have been preserved in methylated spirit in the laboratory.

2. Visit the school garden and make observations on various types of adaptations for fruit and seed dispersal. Draw as many of them as possible.

3. Examine the wool or fur of any conveniently studied mammal—for example, a dog, goat, or cow. Collect and investigate the structure of any seeds and fruits adhering to the animal's coat.

4. Examine bird-droppings on cars, buildings, and so on. Are any seeds present? If so, do the seeds have thick coats or not?

5. Search for fruits and seeds in the school compound and find out how far they are from the nearest possible parent plant. In this way you can estimate the efficiency of seed and fruit dispersal in any particular plant.

6. Go for a walk in the forest or on the farm after a shower of rain. When you return to school, carefully wash off the mud or soil clinging to your shoes or feet into a bowl, and search for any seeds and fruits present in the earth in the bowl. Germinate the seeds and try to identify the plants which grow.

7. Try to assess the abundance of seeds produced by various plants by investigating the yield of easily studied crops such as cocoa and kola nut.

In the case of cocoa (*Theobroma cacao*), count both the number of seeds (beans) per pod and the number of pods per tree. Do all trees on a farm produce the same total number of seeds? What explanation can you offer to account for your results?

Similarly, estimate the total number of follicles on each kola nut tree (*Cola* sp.), and then count the number of seeds ('nuts') present in each follicle. What is the average yield of kola nuts per tree on a farm? What reasons can you offer to explain the fact that some *Cola* trees produce as few as 200 'nuts' in a year, and others produce over 1500 'nuts' per year?

8. Make a detailed investigation of edible fruits and seeds and try to discover the precise botanical nature of the edible parts. For example, what part of the fruit is eaten in the case of the banana, mango, and so on? What is the nature of the yellow succulent structure on the black seeds of the akee apple (*Blighia sapida*)?

CHAPTER TWENTY-NINE

The Structure and Germination of Seeds and Plant Growth Stimuli

THE most important part of the fruit is the seed, for this contains the embryo, which is the very young plant with young stages of the root, stem, and leaves, and it later grows into the mature plant. The *radicle* and the *plumule* are the structures destined to grow into the root and the shoot respectively. The radicle and the plumule are attached to a food reserve and the whole structure is enclosed in a tough protective coat called the *testa*.

The food reserve is usually stored or made in the seed-leaves called *cotyledons*, but in some seeds such as castor-oil (*Ricinus*) the food is contained in a special structure called the *endosperm*. Seeds with endosperms are referred to as *endospermous* as opposed to *non-endospermous* seeds where there is no endosperm and the food is stored in the cotyledons. There seems to be no relation between the presence or absence of the endosperm and the type of germination.

The cotyledons are also important structures since their number in a seed forms the basis for classifying the whole of the flowering plants into the two main classes: these are the *Monocotyledons*, with only one cotyledon (as in maize and rice), and *Dicotyledons*, with two cotyledons (as in mucuna bean, mango, and groundnut).

The mode of germination of a seed is related mainly to the behaviour of the cotyledons during the process. In some seeds the cotyledons stay below the soil and this type of germination is referred to as *hypogeal*. In others the cotyledons are carried above the soil and may turn green and manufacture food for the young plant until the true leaves appear. This type is said to be *epigeal*. We shall discuss below the structure and germination of two seeds showing epigeal germination, namely sword bean (*Canavalia*) and groundnut, and two seeds showing hypogeal germination, namely mucuna bean and maize.

Epigeal Germination

The Sword Bean (*Canavalia ensiformis*) (Fig. 29.1). The sword bean has a large flat seed covered with a thick seed coat, or testa, which may be rather wrinkled when dry. Along its straighter edge is a narrow white hilum, which marks the position where the seed was attached to the pod by a stalk called the *funicle*, which is found on rather young seeds, but which withers away when the seed is ripe.

When moistened the testa can be removed and the cotyledons are found as two flattened structures. When they are carefully opened, the embryo is exposed, consisting of the tiny radicle or primary root at one end and the plumule, folded for protection, at the other end. Between these lies a small central portion (the *hypocotyl*) which is joined to each of the two cotyledons by a short stalk (see Fig. 29.1).

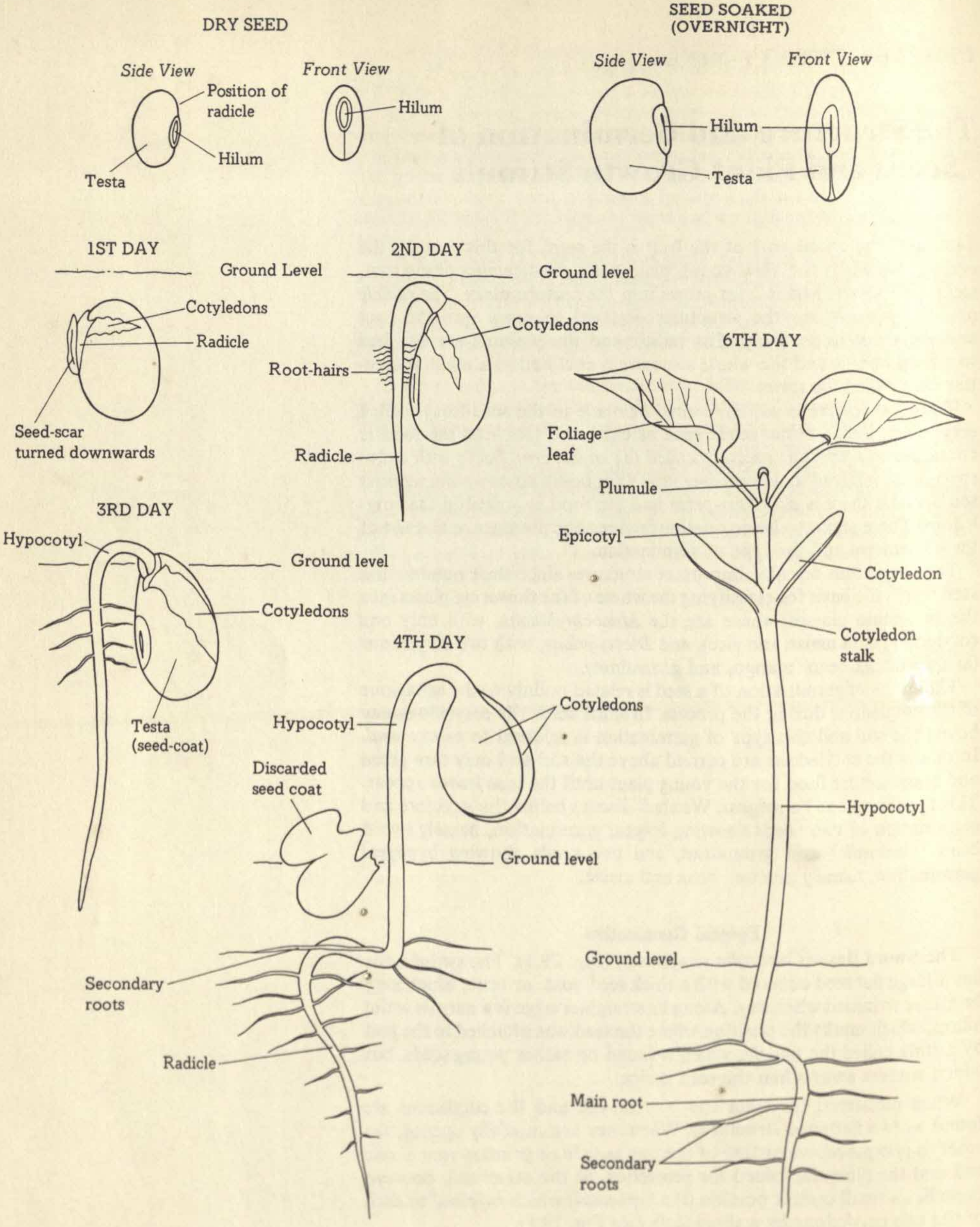


Fig. 29.1. Structure and germination of *Canavalia* seed

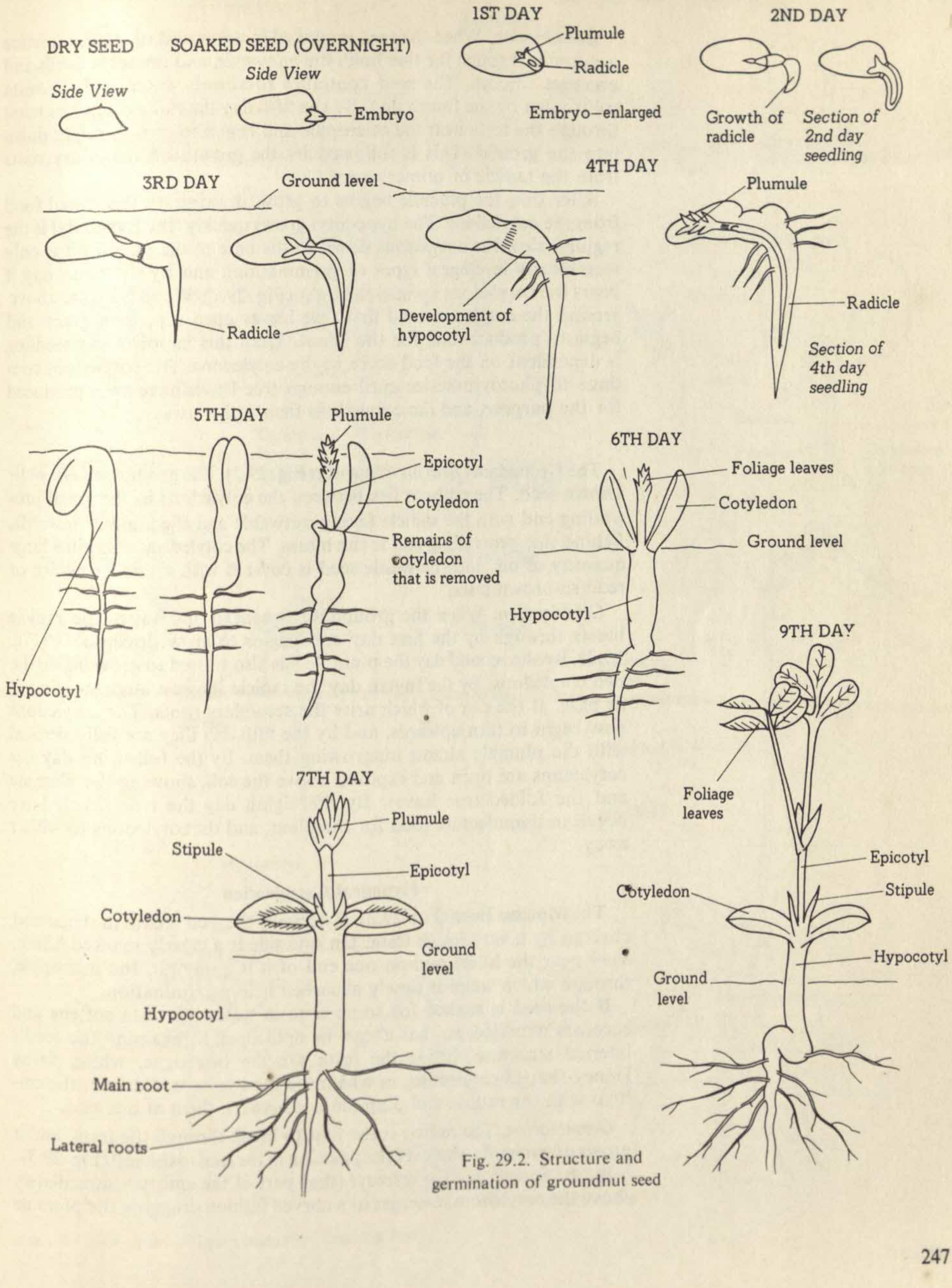


Fig. 29.2. Structure and germination of groundnut seed

Germination. When the seed is soaked in water and planted, moisture penetrates through the tiny hole, the *micropyle*, and the testa swells and becomes smooth. The seed continues to absorb water and the testa splits open by the fourth day. By the fifth day the radicle cap has burst through the testa near the micropyle and begun to grow straight down into the ground. This is followed by the growth of secondary roots from the radicle or primary root.

After this, the plumule begins to grow, drawing on the stored food from the cotyledons. The hypocotyl grows quickly (the hypocotyl is the region below the cotyledons down to the base of the radicle; it is only seen clearly in epigeal types of germination), and by the tenth day it bears the cotyledons up into the light (Fig. 29.1). When they are above ground the cotyledons and first true leaves open out, turn green and begin to produce food for the plant. Until this happens the seedling is dependent on the food store in the cotyledons. The cotyledons continue to photosynthesize until enough true leaves have been produced for the purpose, and the cotyledons then wither away.

The Groundnut (*Arachis hypogea*) (Fig. 29.2). The groundnut is a well-known seed. The embryo lies between the cotyledons in the small protruding end with the radicle facing outwards and the plumule inwards. Behind this protruding end is the hilum. The cotyledons contain a large quantity of oil, and the whole seed is covered with a thin brownish or reddish-brown testa.

Germination. When the groundnut is soaked and sown, the radicle bursts through by the first day and begins to grow downwards (Fig. 29.2). By the second day the plumule has also started to grow inside the two cotyledons. By the fourth day the radicle shows a large swelling at its base, at the end of which arise the secondary roots. The cotyledons now begin to turn upwards, and by the fifth day they are fully vertical with the plumule almost outgrowing them. By the following day the cotyledons are open and exposed above the soil, showing the plumule and the folded true leaves. By the eighth day the true leaves have begun to manufacture food for the plant, and the cotyledons to wither away.

Hypogeal Germination

The Mucuna Bean (Fig. 29.3). Externally the seed is oval in shape and covered by a very tough testa. On one side is a clearly marked hilum. Very near the hilum and on one end of it is a tiny pit, the micropyle, through which water is slowly absorbed before germination.

If the seed is soaked for some time in water the testa softens and becomes wrinkled, so that it can be split open to examine the seed's internal structure. Inside the testa are the two large, white, fleshy kidney-shaped cotyledons, in which the food reserve is stored; the embryo with the radicle and plumule lies between them at one end.

Germination. The radicle is the first to break through the testa, and it grows downwards whatever the position of the seed in the soil (Fig. 29.3).

By the fourth day the *epicotyl* (that part of the embryo immediately above the cotyledons) emerges in a curved fashion dragging the plumule

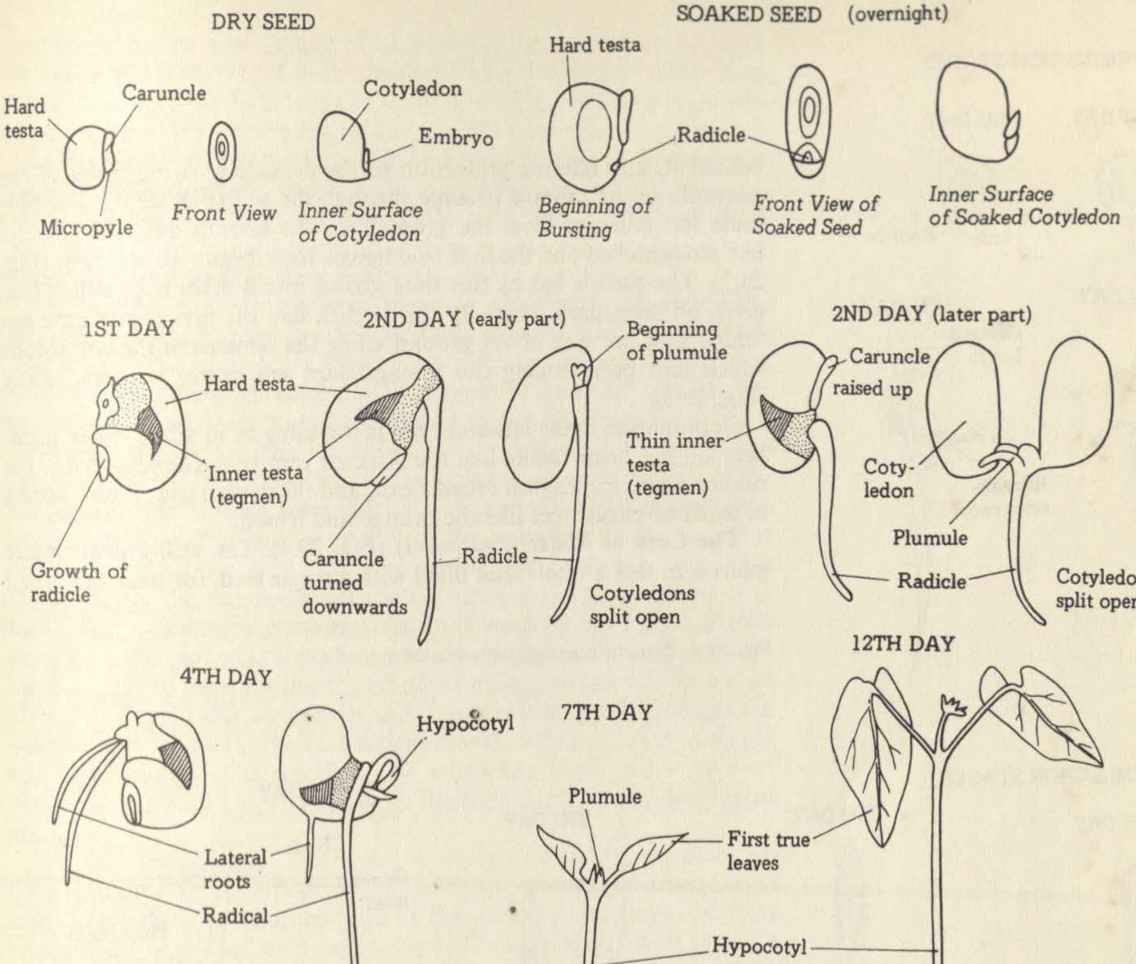
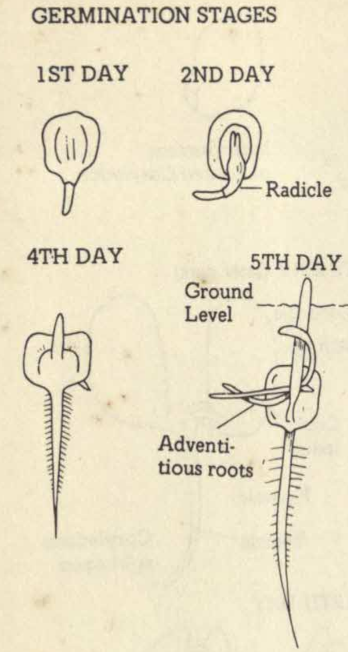


Fig. 29.3. Structure and germination of mucuna bean

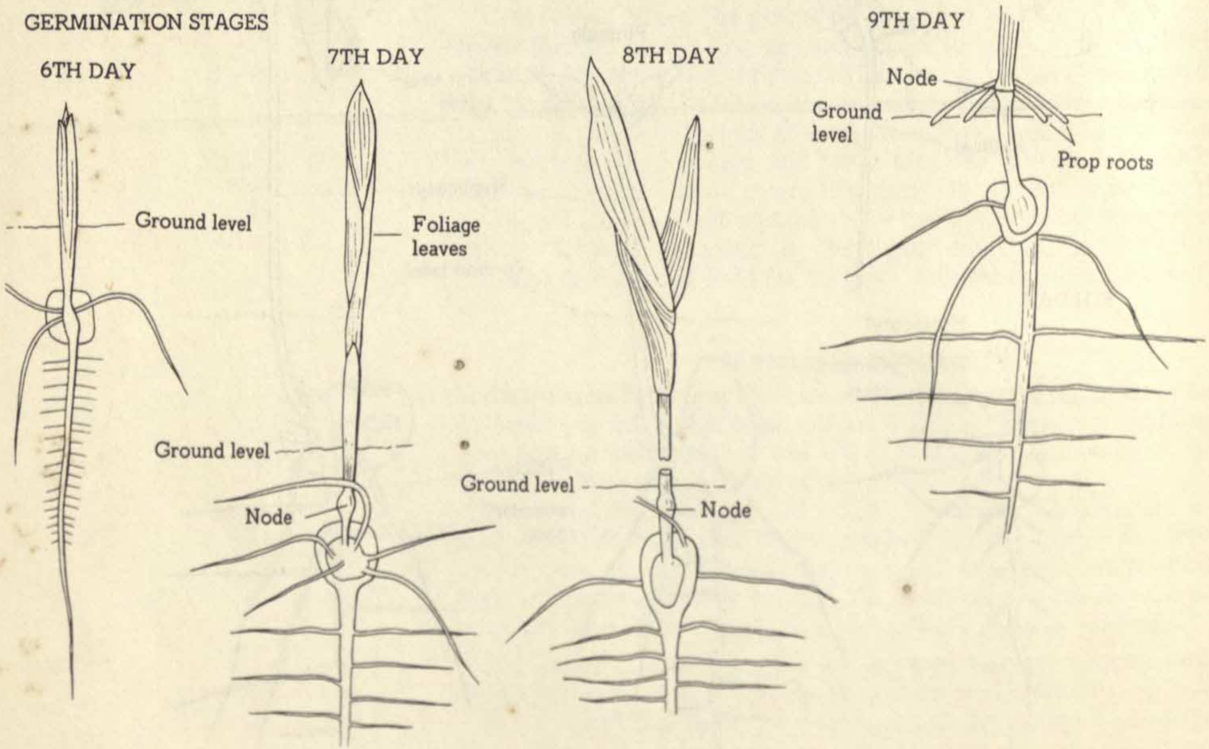


behind it, and offering protection to the delicate growing point of the plumule on its upward passage through the soil (Fig. 29.3). The plumule has emerged from the ground, by the seventh day, the epicotyl has straightened and the first true leaves have begun to develop (Fig. 29.3). The radicle has by this time grown into a main root which has given off secondary roots. By the twelfth day the first leaves have unfolded and are well above ground while the remains of the cotyledons which had been feeding the young plant are nearly withered away (Fig. 29.3).

Germination in the mucuna bean is the same as in some other members of the bean family like the African yam bean (*Sphenostylis*), the runner bean, the English broad bean, and the garden pea; it also occurs in seeds of citrus trees like the orange and lemon.

The Corn or Maize (*Zea mays*) (Fig. 29.4). The well-known maize grain is in fact a whole fruit filled with a single seed, for near the broad

Fig. 29.4. Structure and germination of maize



end may be seen a projecting point which is the remains of the style; this is on the same side of the grain as the whitish oval area which is the embryo. If the fruit is cut longitudinally through the middle of this area, it is found that the embryo lies on one side of a large mass of endosperm, which consists mainly of starch with some little protein. The outermost layer of the endosperm, which is the layer lying just under the testa, is called the *aleurone layer* and contains protein grains. The wall itself, although so thin, is really made up of three layers—the nucellus, integument, and the carpel wall (or pericarp).

The embryo consists of a large plumule, a radicle, and a shield-like structure attached at the junction of these two and with its surface in contact with the endosperm. This is called the *scutellum*, or shield, and is functionally the single cotyledon. The plumule is covered by a sheath, the *coleoptile*, while the radicle is covered by the *coleorhiza* (Fig. 29.4).

Germination. When the maize grain is moistened with water and sown, it begins to germinate by converting the starch and protein of the endosperm into soluble substances which pass through the scutellum into the embryo. This initiates growth of the plumule and radicle, so that within two days the growth of the part of the cotyledon forming a sheath under the radicle causes the covering of the grain below it to burst. The radicle then grows and breaks through the coleorhiza. At the same time the part of the cotyledon above the plumule and the coleoptile grow out to burst the upper part of the grain, and this is followed on about the fourth day by growth of the plumule to break through the coleoptile (Fig. 29.4). The first foliage leaves, which are at first rolled up, then expand. The scutellum or cotyledon stays below ground within the grain, to absorb food from the endosperm for the developing plant.

The first radicle, with prominent root-cap and root-hairs, does not form a main root system as in dicotyledonous seeds, but adventitious roots begin to arise from the base of the coleoptile, to form a fibrous root system typical of monocotyledons. The unfolding leaves are also found to have a sheathing base and a flat, strap-shaped lamina with parallel venation which is typical of monocotyledons. The endosperm and cotyledon now begin to wither away.

Conditions Necessary for Germination

The main factors necessary for successful germination of seeds are:

(*a*) Viable seeds.
(*b*) Water.
(*c*) Air with an adequate amount of oxygen.
(*d*) Suitable temperature.
(*e*) Light in some species.

The processes involved in germination require the expenditure of a great deal of energy. This energy is obtained by the high rate of respiration which accompanies germination, so that factors which increase the rate of respiration also favour rapid germination.

Water. Dry seeds respire rather slowly, but when the seed absorbs water, the rate of respiration is increased and germination readily follows.

Air with Oxygen. The need for air with adequate oxygen does not seem apparent, but when we consider that seeds covered by stagnant and muddy water often fail to germinate, the problem becomes evident. For example, in the germination of the red mangrove (*Rhizophora*) (Chapter 3) the seed needs air for germination though it often falls from the plant into brackish water. To overcome this, germination is begun while the seed can obtain air—*i.e.*, whilst it is attached to the plant.

Temperature. Most plants have an optimum temperature at which germination and growth of the seedling take place most rapidly. Tropical plants require a higher temperature than temperate plants. For tropical plants there is very little difficulty about air temperature, which is nearly always suitable for germination. Maize grains often fail to germinate below 10°C, whilst water-melons require a temperature not lower than 20°C.

Experiments To Demonstrate Conditions Required For Germination

1. Four test-tubes with some cotton-wool at the bottom are set up with maize grains as follows:

(*a*) *Control.* The control experiment here is one lacking none of the factors being studied. Moisten the cotton-wool in the test-tube with water and place some of the maize on it, and then put a light plug of dry cotton-wool in the mouth of the test-tube. Place the experiment in a warm place (room temperature is enough). The seeds in this case have warmth, water, and oxygen, which are all the essentials required.

(*b*) *Without Water.* Place some maize on dry cotton-wool, the mouth of the tube being lightly plugged with more cotton-wool. Leave the experiment at room temperature.

(*c*) *Without Suitable Warmth.* The experiment is set up like that of the control (*a*) except that it is placed in a cold room or in a refrigerator.

(*d*) *Without Oxygen.* Place some maize on the wool and nearly fill the test-tube with previously boiled and cooled water. Pour a layer of oil on the surface of the water to prevent air dissolving in it. Place the experiment in a warm place. Warmth and water are thus provided but not oxygen.

Observe the seeds daily for several days. The seeds germinate only in Experiment (*a*).

2. *Three Beans Experiment.* This is a rather simple way of demonstrating the conditions necessary for germination. Three dry bean seeds are attached to a piece of wood, one at each end and one in the middle. This is placed in a beaker, which is filled with water until the middle seed is half immersed in it. The beaker is then left in a warm place for a few days, while water is added to it from time to time to maintain the original level.

It is found that only the middle bean germinates successfully because it has sufficient moisture, oxygen, and warmth. The seed at the lower end of the wood in the water will not germinate properly because although it has sufficient moisture and heat, it has not enough oxygen. The upper seed also fails to germinate because it has only sufficient oxygen and a suitable temperature, but no moisture.

In order to illustrate the need for a suitable temperature, the same apparatus can be set up but placed in a cold chamber. Germination will then fail.

Plant Growth and External Stimuli

Growth is an increase in size or length of an organism. In our study of the germination of seeds we found the origin of the root and the shoot. Roots usually grow in length downwards and push their way through the soil, while the shoots grow up into the air. It is interesting to know more about some aspects of growth, such as the regions where growth in length takes place, and the effect of external factors such as gravity, light, and water on the direction of growth of young plants. Some of the responses of plants to these factors are called *tropisms*.

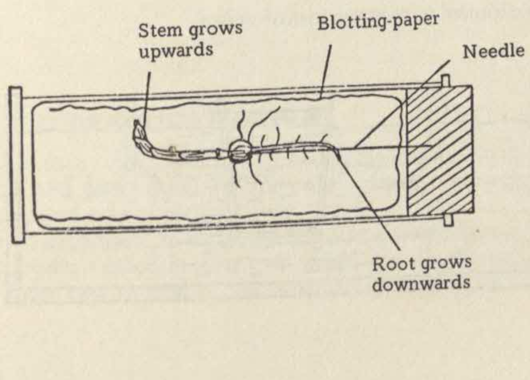
To find the region of growth in a root (Fig. 29.5). Germinate bean seeds in a roll of damp cloth so that the roots are straight. Select one of them, and starting at its tip mark off equal spaces of 1 millimetre each with indian ink. Line a gas-jar with damp blotting paper and then place this seedling between the paper and the glass. After a few hours it is found that as the root grows downwards, the equal spaces of 1 millimetre each are maintained at all the upper positions except close behind the root-tips where the intervals between the marks become wider and wider. This shows that all the growth in length of a root takes place close behind the root-tip. If the tip of the root is cut off growth ceases for a while.

To find the region of growth in a shoot (Fig. 29.6). Select a growing seedling with an upright stem and mark on it with indian ink equal spaces of 5 millimetres. Examine the seedling every few hours and it will be found that as the stem grows, nearly all the marks get farther apart. This shows that growth in stems is not confined to a very short distance as in roots, but that it is spread over a greater length of the stem.

Effect of Gravity on Growth of Roots and Shoots. In whatever position a seed is planted the main root eventually grows downwards and the main stem upwards. This means that roots are positive in their response to gravity (*positive geotropism*) and shoots are negative (*negative geotropism*). These are illustrated by the experiments below.

To show geotropic response in a primary root and shoot (Fig. 29.7). In order to show the effect of gravity on the direction of growth of the root, germinate some bean seeds in a roll of damp cloth and select a seedling with a nearly straight root and stem. Line the inside of a gas-jar with damp blotting paper and pin the selected seedling through its cotyledons to the centre of the

Fig. 29.7. The effect of gravity on a primary root and shoot



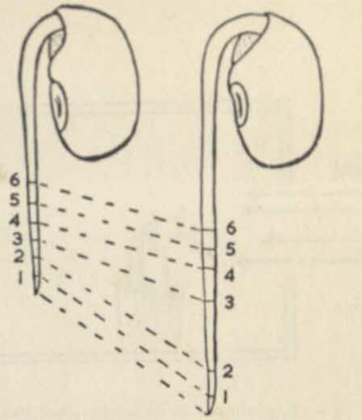


Fig. 29.5. To find the region of growth in a roo

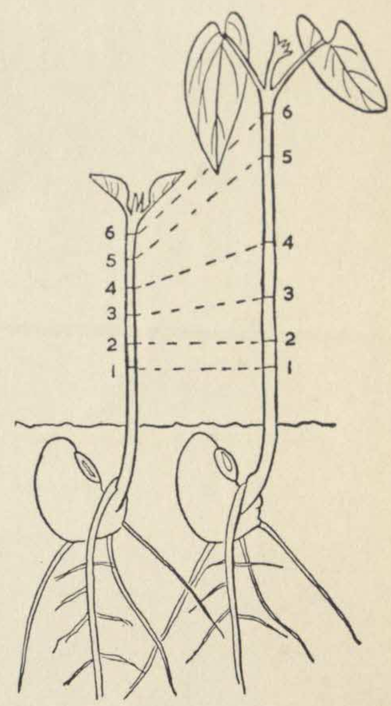
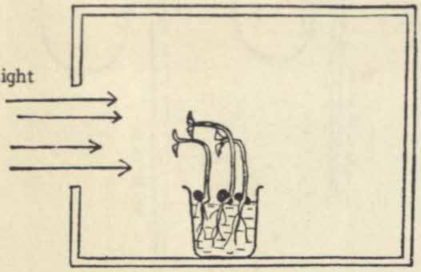


Fig. 29.6. To find the region of growth in a shoo

cork of the gas-jar. Fit the cork to the gas-jar in a horizontal position so that the seedling is horizontal in the centre of the jar. Then place the jar in a dark room. The set-up is thus so arranged that the plant is equally surrounded by moisture on all sides, and the light effect is absent. Another seedling should be pinned on a klinostat as a control.

When observations are made every hour, it is found that the tip of the root turns downwards while the stem bends upwards. The only force which has caused these changes in the direction of growth is gravity. Hence the force of gravity causes roots to grow downwards and shoots upwards.

It is also possible to show geotropic effects in shoots and roots much more simply. A potted seedling is placed on its side in a dark room and left overnight. The shoot grows upwards while the roots on examination will be found to have bent downwards again.



ig. 29.8. Experiment to illustrate phototropism

Effect of light on growth direction of shoots and roots (*Phototropism*) (Fig. 29.8). Shoots generally react positively to the source of light while exposed roots tend to bend away from the light. To show this the following experiment may be carried out.

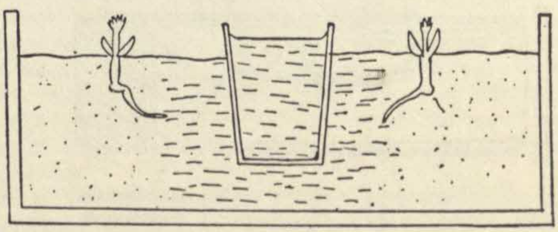
Select some seedlings grown in moist blotting paper so that the stem and roots are straight. Suspend these vertically on a damp, coarse cloth stretched across the mouth of a glass vessel so that the roots dip into water in the glass vessel. Place the vessel in a box which allows no ray of light to enter anywhere except through a hole in one of its sides. After some hours it will be found that the stems bend towards the hole through which light enters, while the roots bend away from the light. If the vessel is turned round through 180 degrees so that the shoots are away from the light, they grow again towards the light.

General Effects of Light on Growth. Light has some striking effects on plant growth in general. This is easy to see when some seedlings of a plant are grown in sunlight and others in darkness. It is found that the seedlings grown in the light are relatively short and robust, are green in colour, and have relatively larger leaves, whilst those grown in the dark are comparatively tall and weak, are white or yellow (they lack chlorophyll), and have smaller leaves.

The latter type of growth is referred to as *etiolation* and is explained by the fact that a plant in the dark has to grow quickly to reach the light in order to increase its rate of photosynthesis since it will otherwise die from lack of food. Trees in tropical forests are so tall because of the competition for light whereas those in open savannas are more spreading.

Effect of Water on Growth Direction of Roots (*Hydrotropism*) (Fig. 29.9). Roots grow towards water and are said to be *positively hydrotropic*. This can be shown by the following experiment.

Fig. 29.9. Experiment to illustrate hydrotropism



Nearly fill a trough with slightly moist soil and place a porous pot in the centre of it. Select about six seedlings germinated in moist blotting paper so that the roots and shoots are straight, and plant them vertically at a fixed distance away from a central porous pot. After a day or two, and before the seedlings begin to show the need for water, partly fill the porous pot with water. After several days, carefully dig out some of the seedlings and observe the nature of their roots. It will be found that the vertical roots have bent towards the porous pot. Use a control experiment, set up in the same way, but put no water in the pot; instead, water evenly all over the box. In this case there is no root curvature.

Factors Necessary for Healthy Growth of Plants to Maturity

We have dealt with the factors necessary for germination of seeds earlier in this chapter, namely water, warmth, and oxygen. But for the healthy growth of plants there are a number of factors which play an important part; these are mentioned below.

(*a*) *Organic Food.* This supplies the energy which is needed for certain life processes, and provides the building material for the formation of new protoplasm. In the plant some of this exists as condensation products of sugars formed by photosynthesis.

(*b*) *Enzymes*, *Vitamins*, and *Hormones*. Although these are present in relatively small quantities, each of them has special functions.

(*c*) *Mineral Salts.* As discussed in Chapter 30 these have special functions in the plant.

(*d*) *Water*. Water is necessary for continued growth as it is the major constituent of protoplasm and without it cell division ceases.

(*e*) *Oxygen*. Oxygen is necessary for active respiration required for growth.

(*f*) *Favourable temperature*. Most plants have a range of temperature outside which they may fail to grow.

Lack of any of the essential factors named above may become a limiting factor and arrest the healthy growth of a plant to maturity and flowering.

SUGGESTED PRACTICAL WORK

1. There are many experiments described in the text in this chapter. Study the structure and germination of one seed showing a hypogeal and one showing an epigeal type of germination.

2. Set up an experiment to show the factors necessary for germination of seeds. Describe the method in your own words and record your results. (*Note:* It is quite easy to modify the 'wormery' described in Chapter Five,

2(*c*), so that it can be used as a germination 'sandwich'. Remove the soil from the 'wormery' and replace with a central sheet of blotting paper. Insert seeds between the blotting paper and the glass. Keep the paper moist, and perform your germination experiments with the 'sandwich'.)

3. Set up or look at demonstration experiments showing the effect of light, water, and gravity on the direction and rate of growth in stems and roots. If your school has a *klinostat* your teacher will use it as a 'control' in experiments to show the effect of gravity. (The klinostat is an apparatus with a motor which keeps turning the shoot or root round and therefore eliminates the one-sided effect of gravity or light.)

4. A simple experiment to discover the amount of water absorbed by a dry seed should be attempted. First of all take twenty dry seeds and weigh them. Next soak the seeds in water overnight, dry them in a cloth, and weigh them again. By subtracting the first answer from the second you obtain the figure for the weight of water absorbed by twenty seeds. Divide this figure by twenty and you have the weight of water absorbed by a single seed.

5. Devise a number of experiments to discover how much food is needed by an embryo during its germination. Choose dicotyledonous, non-endospermic seeds for this work—for example, groundnut seeds. Prepare a graded series of seeds, ranging from those with the full amount of food store to some with virtually no food store, by cutting away various amounts from the cotyledons. Attempt to germinate each seed under identical external conditions, and note the speed and extent of growth of each seedling. Does it seem to you that the groundnut seed needs all its food reserve in order to germinate? Does the seed which has been deprived of its entire food store succeed in growing at all?

CHAPTER THIRTY

Absorption of Water and Mineral Salts and Transpiration in Plants

A PLANT on land is for most of the time in danger of drying out, because of the wind which blows past it and also the heat from the sun. It is therefore important that it should have efficient means of absorbing water from the soil. The water is absorbed through the *root-hairs*, as already described, by means of a physical process called *osmosis*. In order to understand this process we should first of all study the basic physical process known as *diffusion*.

If we succeed in bringing together two solutions of unequal concentrations so that they have a common boundary, the molecules of each solution begin to move and to penetrate the other solution so that eventually the two solutions come to have the same density. The process by which this is brought about is called diffusion. We can perform experiments to illustrate diffusion. If fresh water is carefully poured down the side of a glass containing a strong solution of sugar, the water will form a definite layer on top of the sugar solution since it is less dense. But soon the sugar molecules begin to enter the molecules of the pure water and more water molecules penetrate the sugar solution. Thus the separating line between the sugar solution and the water begins to disappear, and before long the sugar solution and the water reach the same density; if you taste the mixture at various depths you will find that the whole solution has the same degree of sweetness.

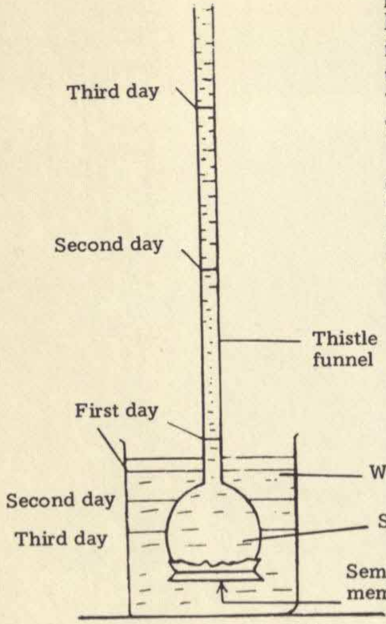
We can make it easier to see how the process takes place if we colour the sugar solution by means of a dye such as red ink. In this case the final colour of the mixture becomes pink. It is possible to have diffusion and achieve the same result even if we placed a membrane such as a slice of bread between the two solutions. A slice of bread is a *permeable membrane*, that is, it has wide pores which can allow the molecules of sugar and water to pass through equally well. But there are other membranes, described as *semi-permeable*, through which water molecules pass more easily than molecules of substances dissolved in the water, which find it very difficult to pass. Thus when any two solutions of unequal densities are separated by a semi-permeable membrane there is a flow of solvent (water) between them, more of the solvent passing towards the stronger solution.

It is this modification of the process of diffusion, brought about by the presence of a semi-permeable membrane, which is often referred to as *osmosis*. Osmosis is therefore the process by which the water of a weak solution is drawn into a stronger solution through a semi-permeable membrane. Examples of semi-permeable membranes are: parchment paper, pig's bladder, skin from inside the shell of a raw egg, sausage-skin, and the film formed by copper sulphate in contact with potassium ferrocyanide.

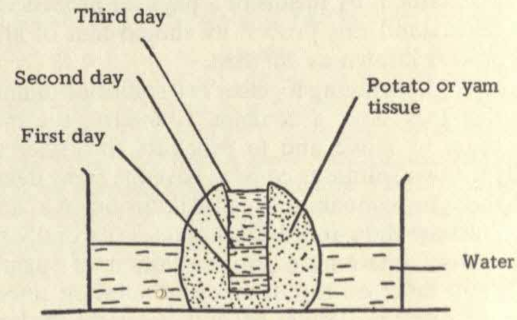
To Demonstrate Osmosis (Fig. 30.1)

Tie a semi-permeable membrane, such as pig's bladder or parchment paper or cellophane, very carefully over the mouth of a thistle-funnel. Invert, and fill the cup of the funnel with sugar solution (or syrup). Then immerse the funnel in distilled water in a beaker. Clamp the arm of the thistle-funnel in a vertical position. Mark the level, and leave for some time. The level of the solution in the funnel rises and the membrane bulges out. This is because water has entered by osmosis.

This experiment can also be carried out using living material. Yam or cassava tubers are suitable for this demonstration, and should be prepared in the following way: cut a segment of the plant tissue and scoop a hollow in the centre as shown in Fig. 30.1. It is important that all cut surfaces of the tuber should be thoroughly washed in running water so as to remove cell



(a)



(b)

Fig. 30.1. Experiment to illustrate osmosis: (*a*) thistle-funnel; (*b*) yam tissue

debris. Next place the prepared tuber segment in a dish containing some water, and add a small quantity of strong salt or sugar solution to the cavity of the tuber. (The level of this solution should be carefully marked on the inside of the hollow, with a pin.) In order to prevent excessive evaporation it is necessary to place a lid over the dish. Observe the level of the solution inside the tuber cavity every day. Does the level of liquid rise or fall? How can you explain the results, in terms of osmosis?

Another simple osmosis demonstration can be performed by using small 'chips' of yam tuber. These are placed in two petri-dishes, A and B. Water is added to dish A, and strong sugar solution is added to dish B; the yam 'chips' (each one should measure 5 cm × 1 cm × 1 cm) should be tested by pressing between the finger-tips, every five minutes. Are both sets of 'chips' equally firm to the touch? Can you explain the results in terms of water movement across a semi-permeable membrane?

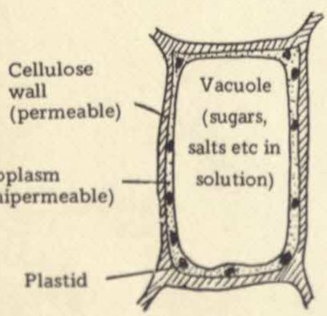


Fig. 30.2. A plant cell showing the permeable and semi-permeable regions

Permeable and semi-permeable membrances and the phenomenon of osmosis are found in cells. The wall of the plant cell is permeable, but the layers which form the protoplast and the lining of the vacuole are semi-permeable (Fig. 30.2). Thus when a cell containing a concentrated solution is surrounded by pure water or a very weak solution, the water will penetrate the cell. The greater the difference between the concentrations of the inner and outer solutions, the greater is the rate of entry. The concentration of a solution is a measure of its *osmotic pressure*, that is, the force with which it can absorb water molecules when in contact with water.

Absorption of Water (Fig. 30.3)

We can now see how osmosis enables roots to absorb water. We have already indicated that the root-hairs, which are prolongations of some of the epidermal cells of the root, are in direct contact with water in the soil (as a dilute solution of mineral salts) either free or held at the surface of the soil particles. The outer wall is permeable but the protoplasm inside it is semi-permeable. In the vacuole is a much stronger solution of sugars and salts than is found in the soil water. That is, the contents of the root-hair cells exert a higher osmotic pressure than those of the soil solution.

Thus the water in the soil readily penetrates the outer cell-wall, and the semi-permeable protoplasm allows the water required by the plant to enter into the vacuole but hinders the flow outwards of the molecules of the more concentrated cell-sap in the root-hair. Thus osmosis occurs and the cell-sap of the *root-hair* becomes diluted until it is weaker than the cell-sap of the cortical cells. The root-hair becomes full of water and is said to be *turgid.* Since the cells of the cortex are less turgid water passes into them from the root-hairs. This procedure goes on successively through the cortex and endodermis until the water reaches the xylem, in which it rises up the plant. In this way water is absorbed by the plant.

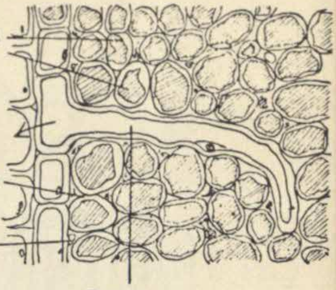
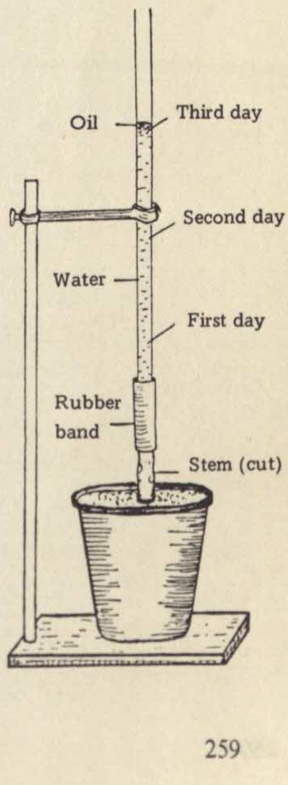


Fig. 30.3. The root-hair in the soil

It has been emphasized that for the root-hairs to absorb water in the form of aqueous solutions the concentration of the sap, or the osmotic pressure inside the root-hair, must be higher than that of the solution outside the root-hair. If the osmotic pressure of the surrounding solution is the same as that inside, there will be no absorption; if, on the other hand, the osmotic pressure of the surrounding solution is greater than that inside, then the root-hair will rather lose water and its turgidity will fall. This eventually will make the plant *wilt.*

It appears that as a result of osmosis the tissues of the roots of certain plants exhibit a phenomenon referred to as *root pressure* (Fig. 30.4).

Fig. 30.4. Experiment to illustrate root pressure



This is clearly shown by the following experiment. Cut the shoot of a plant and firmly attach a glass tube to the stump. Put a little water in the tube and cover the surface with oil to prevent evaporation. Water will continue to be absorbed by the roots and this rises in the glass tube. Root pressure is also demonstrated by keeping a plant in a damp atmosphere when there is no loss of water by the plant (transpiration). Root pressure then forces out water through the leaf-pores and this appears as drops on the leaf. This process is called *guttation.*

Force of Transpiration. It is found that when much water is being lost through the leaves by transpiration a force is set up which is the most important of all the forces responsible for absorption of water from the soil.

Many people have long been amazed that water can rise to the top of trees some of which are several hundred feet high. It is now certain that this is brought about by the force which arises from the loss of water from the leaves—that is transpiration—and which is transmitted throughout the stem to the roots. This force is called *transpiration pull.*

In conclusion, therefore, we may say that water is absorbed by the plant by means of the forces of osmosis, and the transpiration pull. The latter seems to be the most important one.

Absorption of Soluble Mineral Salts

As well as water, plants absorb the following elements in the form of mineral salts from the soil: sodium, potassium, calcium, magnesium, and iron—which are metals—and non-metals such as chlorine, sulphur, phosphorus, carbon, silicon, and nitrogen. We shall consider their use in the plant later. In the absorption of these elements, the semi-permeable membranes of the cells of the epidermis of the root are found to be highly selective—that is, an element that is essential to the plant is absorbed even if its quantity in the soil is relatively small. On the other hand, an element found in relatively large quantities in the soil may only be absorbed in very small amounts. Thus although marine plants are completely surrounded by sea-water they do not absorb the salts dissolved in it in the proportions in which they are present,but accumulate some and restrict the entry of others.

It is also very important to note that only dissolved substances can enter the root; solid particles, however small, will not be absorbed. It is possible to perform an experiment to illustrate this as follows.

Obtain two young herbaceous plants like *Peperomia* (Fig. 23.1) or balsam and place them in two jars containing water, one of which is coloured with red ink which *dissolves* in water, and the other coloured red with carmine, which is *insoluble* in water but remains as very fine particles in it. After a day it is found that the middle of the roots and stem of the plant in the red-ink water are stained red, while those of the plant in carmine water are without the red colour.

The Rise of Water up the Stem. It was mentioned in Chapter 24 that it is the xylem tissues, or wood, which conduct the absorbed water and mineral salts up the stem. The last experiment described can be used to prove that the xylem is the path. When the red-ink solution is absorbed and red lines appear in the roots, stem, and leaves, thin transverse sections of them are cut and examined under the microscope. It is found that it is the wood vessels (the xylem) which are coloured red.

Water Cultures—Essential Elements

Mention has already been made above of the elements needed by the plant. These are called *essential or major elements*. They are absorbed not as free elements but combined as salts such as nitrates, sulphates, and phosphates of calcium, potassium, magnesium, and iron. The water in the soil contains at least small quantities of these salts, and if any of them is wholly absent, this lack is soon recognized by distinctive, unhealthy signs in the plant concerned. These elements are called 'essential' because the absence of any one of them prevents the plant from completing its life-cycle, which means that each of them is directly involved in the nutrition of the plant.

In the laboratory, plants may be grown in various solutions without soil in order to find out the part played by the different elements in the

healthy development of a plant, and thus to know exactly what the requirements of particular plants are. This practice is known as *water culture* (see Fig. 30.5). Complete solutions are supplied, containing all

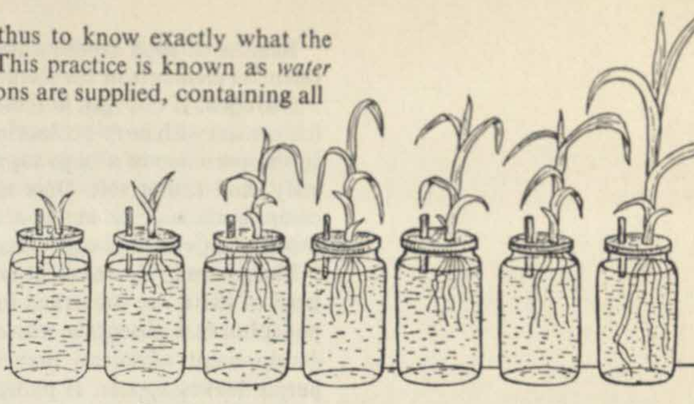


Fig. 30.5. Water culture experiments

the salts which are known to be essential to plants; also other solutions with one of the essential elements missing may be made up and plants grown in them.

One of the best-known culture solutions is Knop's solution. This is made up as follows as a complete solution:

Distilled water	1000 c c
Calcium nitrate	1·00 g
Magnesium sulphate	0·25 g
Acid potassium phosphate	0·25 g
Potassium nitrate	0·25 g
Ferric chloride	a few drops

Incomplete solutions are made by modifying the complete solution as follows.

To omit *nitrogen*, calcium and potassium sulphates are used in place of calcium and potassium nitrates.

To omit *phosphorus*, potassium phosphate is excluded.

To omit *potassium*, sodium salts are used in place of potassium salts.

To omit *calcium*, sodium nitrate is used in place of calcium nitrate.

To omit *magnesium*, sodium sulphate is used in place of magnesium sulphate.

To omit *iron*, ferric chloride is left out.

To omit *sulphur*, magnesium nitrate is used in place of magnesium sulphate.

The plants (ideally, several should be grown in each solution) can first be planted in racks of *very* clean, sterilized test-tubes, but may later be transferred into jars covered with black paper to prevent the growth of algae. Sunflower and maize seedlings are quite suitable but leguminous plants are not to be used for this type of work. Rooted cuttings of *Commelina* are also suitable. Generally it is better to use a seed without much food reserve and one which grows quickly. As soon as the first foliage leaves appear, observations should begin and descriptions and drawings should be made. It is important to change the solutions every week, and to add distilled water as needed to maintain levels. The solutions should be aerated daily, because roots need oxygen.

From time to time the height of each plant in the series of bottles is measured and a note is made of any special features shown by each of the plants in the incomplete solutions. These include signs of chlorophyll deficiency, withering or spotting of leaves, death of the apex of the stem, and poor root development. Comparison should always be made with the plants in the complete solution.

Results of such experiments show the following specific roles of the essential elements in the metabolism and development of the plant.

Nitrogen. If nitrogen is absent the seedlings show yellowing of leaves (chlorosis) with purple colouring; the plant stops growing and later dies. In the presence of a large supply of nitrogen, the plant becomes large, leafy, and rather soft. Once nitrogen is in the plant it is formed into compounds such as amino-acids which are used in the formation of protein, an essential constituent of protoplasm.

Phosphorus. This element works hand in hand with nitrogen, since both of them are concerned in the formation of many proteins. When phosphorus is absent the whole activity of the plant is arrested and the development of lateral branches stops; symptoms such as reddish-purple leaves appear. If phosphorus is added to the soil, it assists in root formation and branching of the shoot, and also induces the early production of profuse flowers and seeds.

Sulphur. Absence of sulphur results in stunted growth of the plant and the formation of yellow patches. This is commonly found in the tea plant, where it is called 'tea yellow'. Sulphur is required for the formation of certain amino-acids.

Calcium. This element is used in the formation of the cell-wall and thus provides the skeleton of the plant. Its absence results in poor development of young leaves at the apex of the plant.

Potassium. Potassium is concerned in the synthesis of carbohydrates and protein metabolism in young leaves. Its absence results in chlorosis or yellowing of leaves at the margins and tips.

Magnesium. This element is essential in the formation of chlorophyll and helps the activity of enzymes. Its absence results in chlorosis of the older leaves; the magnesium in these is transferred to the young leaves.

Iron. Iron is not used in the structure of chlorophyll as is magnesium, but its presence is required during the formation of chlorophyll. Absence of iron in the plant is shown by symptoms of chlorosis with the leaves looking very pale.

Trace Elements

Many experiments conducted with complete solutions of essential or major elements on plants have shown that the plants may begin to develop signs of poor growth after some time. This means that the plant needs something apart from these pure elements. By means of very fine techniques it was found that there were certain elements which were required in very minute quantities, or traces, before the healthy growth of the plant was possible. These elements were called *trace elements*. Examples are cobalt, copper, boron, zinc, and manganese.

Transpiration in Plants

Transpiration is the process by which the plant loses water in the form of vapour. Most of the water vapour escapes through the *stomata* in the leaves, but some of it also diffuses through the epidermal cells and their covering of cuticle; in woody plants, some water is also lost through the lenticels on twigs and branches. Since most of the water is lost through the stomata the term 'transpiration' is now more closely associated with stomatal transpiration.

Stomata have been described in Chapter 26 as tiny pores in the epidermis of leaves, each pore being surrounded by a pair of special cells called guard-cells (Fig. 26.7) which control the size of the stomatal pores. The presence of stomata makes the leaves suitable for exchange of gases which goes on during photosynthesis and respiration, and this makes loss of water inevitable. The behaviour of the stomata and the rate of transpiration are determined by environmental factors. Transpiration exerts a force against that of gravity, and this (known as transpiration pull) enables water to be absorbed.

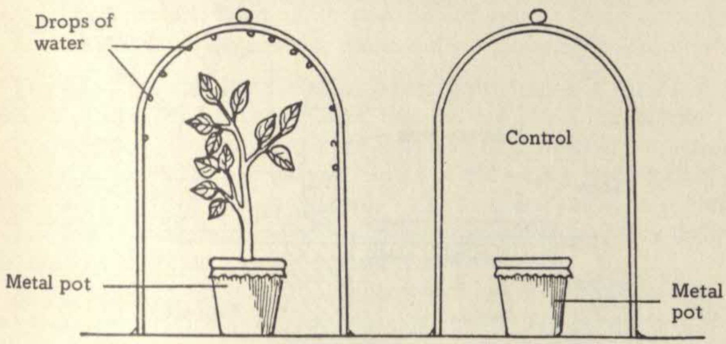


Fig. 30.6. To show transpiration of a potted plant

To show that water vapour is given off by plants. *Potted plant* (Fig. 30.6). Select a potted plant and cover the pot and base of stem with cellophane or rubber. Place the potted plant on a Vaselined glass plate, invert a bell-jar over the pot and plant, and leave them outside the laboratory. Set up a control experiment with no plant. After an hour or so, drops of colourless liquid are seen inside the bell-jar with the plant. To show that these drops are water, touch them with anhydrous copper sulphate—which is white—and its colour changes to blue. No drops of water are found in the control experiment where there was no plant.

Single Leaf: by Use of Cobalt Chloride Paper. Paper containing cobalt chloride is blue when dry and pink when wet. A pair of filter-papers treated with cobalt chloride and dried until they are blue in colour are placed one on either side of a leaf attached to a low plant. The papers are then protected from the water vapour in the outside air by means of transparent covering, such as microscope slides clamped together. Soon it is found that the blue cobalt chloride papers begin to turn pink, particularly on the under-side of the leaf where the stomata are more numerous in most leaves. This shows that the leaves give out water vapour mainly from the stomata.

Measurement of Transpiration. The rate at which water is lost by the plant can be determined in various ways including (*a*) weighing of potted plants, (*b*) weighing a twig, dipping in a test-tube of water, over a period of time, and (*c*) measuring the volume of water absorbed from a *potometer* (on the assumption that the water absorbed is equal to the water lost in the same period). Some of these methods will be described.

Transpiration in a Whole Potted Plant. A well-watered potted plant is placed in an aluminium pot-cover and a polythene bag is tied round the vessel as well as the stem. This prevents loss of water by evaporation from the pot. The

whole plant and the pot are weighed together at regular intervals of, say, thirty minutes for several hours during the day. It is noticed that there is a continuous loss of weight due to loss of water from the uncovered parts of the stem and the leaves.

Transpiration in a Twig (Fig. 30.7). This is a quick weighing method. A twig is placed in a test-tube with water and the surface of the water is sealed off with a layer of oil. A string is attached to the test-tube which is hung on a spring balance. The weight is taken at short intervals. It is noticed that as water is lost by the twig, the weight of the whole apparatus decreases.

Fig. 30.7. Measuring transpiration in a twig

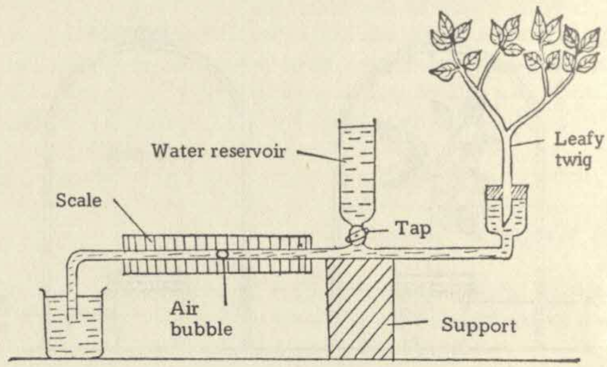


Fig. 30.8. The potometer

The Potometer (Fig. 30.8). A potometer is an apparatus which really measures the rate at which water is absorbed by a plant, but it is used to measure transpiration by assuming that the rate at which water is absorbed is the same as the rate of transpiration. In this method the base of a cut shoot is placed in a closed container of water bearing a graduated tube on which the quantity of water absorbed is measured.

Effect of Environmental Conditions on Transpiration. Various environmental conditions are known to affect the rate of water loss by the plant. As a result of this the rate of transpiration of a plant, or of any leaf, varies from day to day, from hour to hour, and frequently from minute to minute, as the factors of the environment change. The important environmental factors which affect the rate of transpiration are light, humidity, temperature, and wind.

Light. The principal effect of light on transpiration is through its influence on the opening and closing of stomata. In most plants the stomata are closed in the absence of light, so that transpiration through them is very low during the hours of darkness. On the other hand the stomata are open in the presence of light and transpiration is therefore increased in daylight.

Humidity. The amount of water vapour in the air, and the temperature of the air at any time, influence the rate of transpiration. In general, the greater the vapour pressure of the atmosphere the slower is the rate of water loss by the plant, while the rate increases in a drier atmosphere.

Temperature. Another rather indirect effect of sunlight is to increase the temperature of the leaves above that of the atmosphere. This rise in temperature results in an increase in transpiration rate. Low tempera-

ture, on the other hand, lowers the rate of water loss.

Wind. Usually an increase in the velocity of the wind results in an increase in the rate of transpiration by dispersing any accumulated water vapour from around the leaf, whilst a quiet atmosphere retards the rate of diffusion of water through the stomata to the outside, because water vapour often accumulates around the leaves under such conditions. In addition, the wind sways and bends the branches and shoots, and flutters the leaves; such movements also result in increased transpiration. Finally, winds of very high velocity can actually retard the rate of transpiration since the stomata tend to close under such conditions.

Transpiration and Plant Habit. Where transpiration is excessive the plant will wilt, and it can be seen that certain plants are adapted to withstand such conditions, and are thus able to grow in dry situations. Such plants are called *xerophytes*. Some of the ways by which they reduce water loss are by having leaves with thickened cuticle, a covering of hairs, or by possessing rolled leaves with stomata on the inner surface. Examples are cactus, *Euphorbia*, and *Ammophila*.

At the other extreme are the plants which live in damp situations, or in water, and which may have stomata only on the upper surface of their leaves. Such plants are called *hydrophytes*. Examples are the water-lettuce and *Nymphaea* (see Chapter 3).

SUGGESTED PRACTICAL WORK

Attempt a number of the experiments described in this chapter. Your teacher will set up some of them as demonstration experiments.

Make notes on the results of the experiments which you try yourself, noting particularly where the experiment fails to behave as expected; in such cases try to account for the failure.

Arrange to visit an oil palm research centre and a citrus plantation and ask to see evidence of mineral deficiencies (for example, magnesium or zinc 'starvation'). Try to discover something about the use of sprays for foliar feeding.

CHAPTER THIRTY-ONE

Photosynthesis, Respiration in Plants, and the Carbon Cycle in Nature

PHOTOSYNTHESIS is the process by which green parts of plants make carbohydrates and other compounds containing energy from the supplies of free carbon dioxide and water, using sunlight as a source of energy. We have often emphasized that this mode of obtaining food is a fundamental characteristic of green plants and distinguishes the latter from animals. In the process of photosynthesis, the green chloroplasts absorb energy from sunlight, and this is used in breaking down water. Hydrogen is thus released, which enables carbon dioxide to be broken down and which also combines with carbon and some of the oxygen to form a simple sugar such as glucose. Some oxygen is given off during the process. The usual equation is:

$$\underset{\textit{carbon dioxide}}{6CO_2} + \underset{\textit{water}}{6H_2O} + \underset{\textit{energy}}{\text{sunlight}} \rightleftharpoons \underset{\textit{glucose}}{C_6H_{12}O_6} + \underset{\textit{oxygen}}{6O_2}$$

Photosynthesis is much more complex than the brief outline given here. Some of the simple sugar first formed is used in respiration, while the remainder is converted into more complex carbohydrates like starch and cellulose, which may be stored in the stems or roots of the plant. This process often goes further, resulting in the formation of fats and organic acids from the carbohydrates after loss of some of the oxygen. Finally amino-acids may be formed, which may also be combined with each other to form proteins.

Without photosynthesis there would be no food substance for plants and since animals ultimately depend upon plants for their food, life would cease. Animals also derive much of the oxygen needed for respiration from plants. In general, starch is produced only during the hours of daylight; at night photosynthesis ceases and the insoluble starch is reconverted into soluble glucose and transported around the plant to positions where it is needed or where it is stored.

Experiments To Illustrate Features of Photosynthesis

(a) To show that light is necessary for photosynthesis.

(i) *Test for starch in a leaf.* Place two potted plants in a dark cupboard for about forty-eight hours, making sure that the cupboard is not airtight. Since photosynthesis does not take place in the dark, all the starch originally in the leaves is utilized during this period, so that after forty-eight hours the leaves are said to be 'de-starched', that is, they do not contain starch. Then expose one of the two plants to sunlight for a few hours. Pluck one leaf from each of the two plants and test for starch in the following way.

Quickly kill the leaves by dipping them in boiling water. Extract the chlorophyll from them by soaking them in methylated spirit and boiling over a water-bath until the leaves become colourless. Then remove them from the alcohol and dip in warm water for a few minutes to soften them. Add a few

drops of iodine solution to the leaves. They turn blue-black if starch has been formed in them, but yellow if none is present.

In this experiment the leaves which were exposed to sunlight turn blue-black, showing the formation of starch in light, whereas the leaves kept continuously in the dark give only the yellow colour with iodine. Therefore light is essential for photosynthesis.

(ii) Another way of showing the need for light is by fixing two corks on a leaf that is still attached to the plant. After two days, remove the corks and test for starch as described above.

(*b*) **To show that carbon dioxide is necessary for photosynthesis (Fig. 31.1).** Use two young potted plants which have been kept in the dark to make the

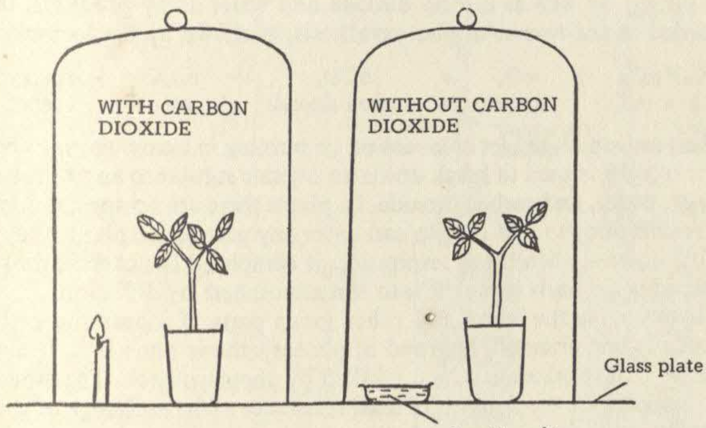


Fig. 31.1. Experiment to show that carbon dioxide is necessary for photosynthesis

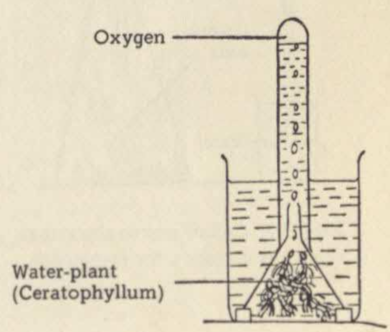
leaves starch-free. Place each of them under a large bell-jar, and put these on Vaselined glass sheets. Along with one of the plants is placed a lighted candle which will use up the oxygen under the jar in combustion and replace it with carbon dioxide. Beside the other plant is placed a dish of caustic soda to absorb the carbon dioxide in the air under the bell-jar. After leaving these two in the light for a few hours, some leaves are removed from each plant and tested for starch. It is found that the leaves of the plant surrounded by plenty of carbon dioxide show the presence of starch, whereas the others without carbon dioxide have no starch. Therefore carbon dioxide is necessary for photosynthesis.

(*c*) **To show that chlorophyll is necessary for photosynthesis.** Select a leaf from a plant which has variegated leaves such as ice-plant or panax, and note the positions of the white patches without chlorophyll. After the leaf has been in sunlight for some time, test for starch in the usual way (as above), and it will be found that only the green parts containing chlorophyll show the positive reaction to iodine. Therefore chlorophyll is essential for photosynthesis.

(*d*) **To show that starch is formed during photosynthesis.** This is described under (*a*) above.

(*e*) **To show that oxygen is given out during photosynthesis** (Fig. 31.2). Fill a glass beaker with water through which carbon dioxide has been bubbled for some time. Place in it some green water-weed like *Elodea* or *Ceratophyllum* and put it in bright sunlight outside. Fit a funnel on the plant and invert a test-tube filled with water over the funnel. After some time, bubbles of colourless gas are formed on the leaves and they rise and collect in the test-

Fig. 31.2. Experiment to show that oxygen is given out during photosynthesis



tube. When sufficient gas has collected in the test-tube remove the latter, closing the mouth with the thumb. Test the nature of the gas by placing a glowing wooden splinter in the test-tube; it bursts into flame, showing that the gas is largely oxygen. Thus oxygen is given out by plants during photosynthesis.

Respiration in Plants

We have already emphasized that respiration is a process common to all living things and that the basic reactions take place within the tissues themselves. The easiest aspect of it to detect is gaseous exchange. Respiration is the process by which food substances are broken down to set free energy as well as carbon dioxide and water as by-products. It is regarded as the reverse of photosynthesis, as shown by the formula:

$$\underset{\textit{glucose}}{C_6H_{12}O_6} + \underset{\textit{oxygen}}{6O_2} \rightleftharpoons \underset{\textit{carbon dioxide}}{6CO_2} + \underset{\textit{water}}{6H_2O} + \underset{\textit{energy}}{\text{energy}}$$

Respiration resembles combustion or burning in many ways. In both cases oxygen is used to break down an organic substance and to release energy, water, and carbon dioxide. In plants there are no special organs for respiration, so that oxygen can enter any part of the plant body by diffusion, and when tissue respiration is completed the carbon dioxide released is similarly given off into the atmosphere by diffusion.

However, in the leaves and other green parts of plants the carbon dioxide is not given off, but used in photosynthesis when light is available, so that respiration is here masked by photosynthesis. The stomata and lenticels are the channels of least resistance to the exchange of gases. Respiration is faster in animals than in plants.

Germinating seedlings, flower buds, and the mycelia of fungi have fast rates of respiration among plant tissues, and are therefore often used to demonstrate the process. The flower buds of the pawpaw (*Carica*) are particularly suitable.

Experiments to Illustrate Features of Respiration

(*a*) **To show that oxygen is used in respiration.** *Germinating Seeds* (Fig. 31.3). Maize grains, soaked in water for about a day until they are fully swollen, are placed in a conical flask together with a test-tube containing caustic soda. The caustic soda will absorb any carbon dioxide which will be released as a result of respiration of the grains. A delivery tube is connected through the cork of the conical flask and its other end dips into a beaker of water as shown in Fig. 31.3. A control experiment is set up without maize grains. After some time, it is found that the water in the beaker rises in the delivery tube, indicating that some gas has been removed from the air in the flask containing the maize grains. When a glowing taper is put into the flask it fails to burst into flame, showing that nearly all the oxygen has been used up. On the other hand, a glowing taper continues to glow in the control flask without maize grains, where no water rise is observable. Therefore, oxygen is used up by respiring seedlings, and for that matter by respiring plant tissues.

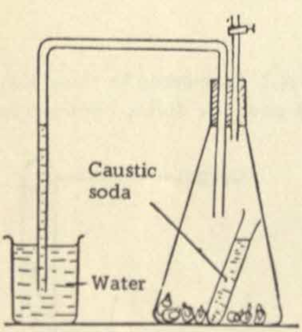


Fig. 31.3. Experiment to show that oxygen is necessary for respiration

(*b*) **To show that carbon dioxide is produced by respiring plant tissues.** About six or more jars are chosen and into each is placed one of the following: leaves in water, germinating seedlings, flower buds, a tap-root, an onion

bulb, a rhizome, and a tuber. Another jar is also provided as control, that is, without any plant material. Into each of these jars is placed a small beaker containing lime-water. All jars are corked and placed in a dark place to avoid any light effects. After some hours it is found that the lime-water in all the jars containing plant material has turned milky. This shows that more carbon dioxide has been released by the plants. (Carbon dioxide turns lime-water milky.) The last jar with no plant material, which is the control, is the only one in which the lime-water fails to turn milky.

(*c*) **To show that heat is produced by respiring seedlings** (Fig. 31.4). Some groundnut seeds are soaked overnight and placed in a vacuum flask. A ther-

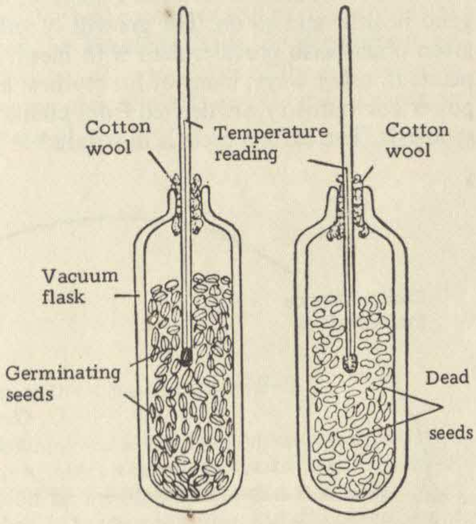


Fig. 31.4. Experiment to show that heat is produced by respiring seedlings

mometer is inserted in the flask so that its bulb is covered by seeds. Plugs of cotton-wool are placed in the neck of the flask to hold the thermometer and to allow entry of air into the flask. A control is set up in a similar way except that here the groundnuts which are placed in the vacuum flask have been killed by boiling in water and then soaked for some time in formalin to prevent them from decaying.

The thermometer readings are taken at the beginning of the experiment, and then daily. It is found that the temperature of the unboiled seeds rises from day to day while that of the boiled seeds shows only slight variation. This shows that heat is produced by respiring seeds. Non-living material does not respire.

The Carbon Cycle in Nature

We have seen from our study of photosynthesis and respiration that Nature has a way of balancing the exchange of carbon dioxide and oxygen, and this is improved further by other processes like burning and decay. By means of these processes the amount of carbon dioxide in the air, which is only 0·03 per cent, is kept fairly constant. Thus a

carbon cycle is said to exist in Nature, and this plays an important part in the interdependence of plants and animals, and in their food chains (see Chapter 2).

The green plants cover a large proportion of the surface of the earth and use up millions of tons of carbon dioxide for photosynthesis. They take in the carbon dioxide constantly being made available as a result of burning, breathing, and decay, and produce large quantities of oxygen in place of the carbon dioxide. The oxygen is used by both the plants and animals in respiration. Some of the food substances produced by photosynthesis are used by the plant itself in respiration, to obtain energy for growth and for other life processes; some of the rest is used as food by animals, including man, for the same purpose of growth, good health, and so on. The growth of other animals which feed on green plants also provides man with meat. Man depends still more on plants in other ways; many of his clothes, and the coal which gives him power for industry, are derived from plants and ultimately from photosynthesis. The carbon cycle is illustrated in Fig. 31.5.

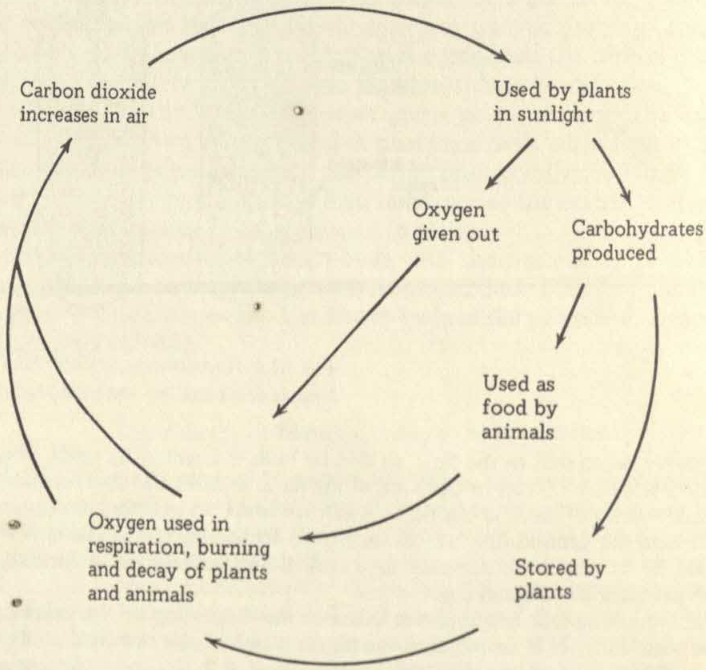


Fig. 31.5. The carbon cycle

SUGGESTED PRACTICAL WORK

1. Set up some of the experiments described in this chapter on photosynthesis and respiration.

CHAPTER THIRTY-TWO

The Soil and the Nitrogen Cycle

THE soil forms the environment of the roots of most flowering plants, and provides them with the essential mineral salts and water as well as the oxygen which the roots need for respiration. It is also the home of an enormous number of organisms, whose activities, in one way or another, affect the growth of the plants. The soil contains small particles (mineral matter) formed as a result of the breaking-down, or weathering, of rocks by heat, cold, wind, and rain. The top layer of the soil contains a high proportion of decaying remains of plants and animals, known as *humus*. The various components of soil are:

(1) Mineral matter.
(2) Humus.
(3) Water.
(4) Air.
(5) Living organisms.

Determination of the Constituents of Soil

Every given sample of soil contains the above five constituents in different proportions. Thus it is useful to be able to determine what these proportions are in any type of soil. It should be mentioned here that it is much more difficult to determine the number of living organisms, but determination of the other four constituents is easier and will be described below.

To determine the amount of air in a soil. Find the volume of a small tin by filling it with water and pouring the water into a measuring cylinder. Call this volume a. Fill the tin tightly with soil, press it down, and add more soil until it is impossible to press it any further. Level off the soil at the top and then scrape it into a large measuring cylinder containing 200 cc of water. Stir until air bubbles cease to appear. Let us call the new volume b.

Then calculate the amount of air as follows:

$$\begin{aligned} &\text{Volume of soil with air} &&= a \\ &\text{Volume of soil without air} &&= b - 200 \\ &\text{Volume of air} &&= a - (b - 200) \end{aligned}$$

This can be expressed as a percentage of the soil, thus:

$$\frac{a - (b - 200)}{a} \times 100$$

To find the amount of (*a*) water and (*b*) humus in a soil.

(*a*) Find the weight of a silica dish (x grammes). Place in it a quantity of soil and weigh again (y) in order to know the weight of the soil ($y-x$). Place the dish and soil in an oven at a temperature of 105°C for about 12 hours, after which all the water will have evaporated. Remove the soil from the oven, cool in a desiccator, and weigh again (z grammes). There will be a loss in weight

due to loss of all water. Repeat the heating and weighing for further periods until a constant weight is obtained.

Calculate the amount of water as the difference between the weight of the damp soil $(y-x)$ and the oven-dry soil $(z-x)$, namely $(y-x) - (z-x)$ gm. The result should be expressed as a percentage of the damp soil, thus:

$$\frac{(y-x) - (z-x)}{(y-x)} \times 100 = \frac{y-z}{y-x} \times 100$$

(*b*) After determining the amount of moisture, transfer the dish and the oven-dry soil into a furnace and heat to redness (ignition). The humus begins to burn, and after about thirty minutes the smoke will have stopped. Remove the dish from the furnace, cool it in a desiccator and weigh (k). Repeat until the weight is constant. The loss in weight $(z-k)$ is the weight of the humus. Therefore

$$\text{Percentage of humus in soil} = \frac{(z-k)}{(y-x)} \times 100$$

To show the presence of microscopic living organisms in soil. For this experiment you need three conical flasks with tightly fitting corks, some fresh clear lime-water, and a supply of garden or field soil. Take enough soil to half-fill a flask and bake it in a really hot oven for about an hour. Then place the cooled baked soil in one flask and an equal quantity of fresh soil in another flask. Suspend a small tube of the lime-water in each flask, including the one with no soil, and cork tightly. Put all the flasks in a dark place for a few days and then note any change in the colour of the lime-water. Try to explain your results.

Types of Soil

Soils may be classified roughly according to the proportions of the different sizes of particles, and on this basis we have *sandy* and *clayey* soils. Sandy soils are composed largely of sand with gravel, while clayey soils consist mainly of clay and silt, which have much finer particles than sand. There is a third type of soil called a *loam*, which consists of a mixture of sand and clay with a certain amount of humus. The high proportion of humus makes this the most fertile type of soil.

It is possible to determine the relative proportions of the soil particles in a given soil by the process of *sedimentation*. To do this, a quantity of soil is shaken up in water in a large measuring cylinder and allowed to settle out into layers. At the bottom will be the larger and heavier gravel followed by the sand on top of it; then comes the silt and finally the finest particles, forming the clay. The depth of each of these layers gives an indication of its relative proportion in the sample of soil.

The relative proportions of the different sizes of particles in a soil determine its *texture* and this affects various properties of the soil such as the amount of water that can be retained by it, the rate at which water can rise in the soil (*capillarity*), the extent to which the soil can be drained and, finally, the porosity or the number of air spaces in the soil.

PROPERTIES OF SANDY AND CLAYEY SOILS

Sandy Soil	*Clayey Soil*
Can retain very little water, thus easily drained.	Can retain a lot of water, thus difficult to drain.
Water cannot rise in it to a high level (poor capillarity).	Water can rise in it to a high level (good capillarity).
It is well aerated because of the large air spaces, and dries out easily.	It is poorly aerated because of very tiny air spaces, and does not dry out easily.
It is poor in plant food (dissolved salts).	Rich in plant food (dissolved salts) which may not be readily available.

Properties of loam. As mentioned above, a loamy soil is the best type of soil for plant cultivation. Its properties combine the best in sandy and clayey soils. It also contains humus.

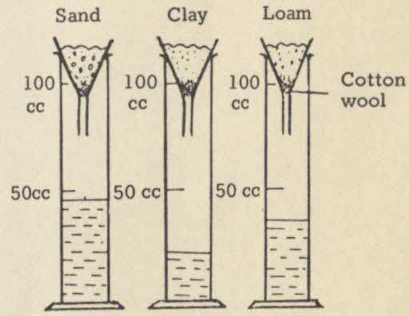


Fig. 32.1. Experiment to compare the water-retaining capacity of sand, clay and loam

Experiment to compare the water-retaining capacity of sand, clay, and loam (Fig. 32.1). Stand a filter-funnel in the neck of each of three 100-cc measuring cylinders and place in each funnel the same weight of sand, clay, or loam soil. Pour on to each 50 cc of water and let it drain through until all drops cease. Then record the volume of water that has drained through in each of the cylinders. The volume of water retained by the soil in each case is 50 cc minus the quantity of water which drained through.

Experiment to compare the rise of water by capillarity in sand, clay, and loam (Fig. 32.2). Three long glass tubes are each tightly packed with dry

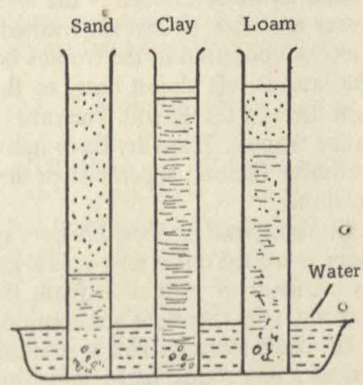


Fig. 32.2. Capillarity of various soils

sand, clay, and loam soil. One end of each is plugged with glass wool and all are immersed vertically in a large vessel containing water. Observations are made on the levels of the water as it rises in the tubes of soil. It is found that at first the water rises by capillarity fastest in the sand, followed by the loamy soil, and is slowest in the clay soil. But after a day or two, the water fails to rise any farther in the sand, whereas in the clay it continues to rise until it reaches the very top of the tube; the level in the loam continues to be intermediate but may later reach the top of the tube as in the clay.

In Nature, the water-retaining capacity of the soil and capillarity play important roles in movement of water in the soil. When it rains, the water percolates through the tiny air spaces and dissolves some mineral salts from the soil particles. As it sinks into the subsoil it may be retained as ground water, and from here it is able to rise by the process of capillarity.

Soil Fertility

We have seen above that the fertility of the soil depends on the presence of humus, mineral salts, water, air spaces between the soil particles, and the proportions of sand and clay. Thus the principal ways in which soils lose their fertility include (*a*) loss of organic matter (humus), (*b*) leaching of mineral salts, and (*c*) erosion.

Loss of Organic Matter (*humus*). In tropical soils when the ground is cleared of vegetation it is exposed to direct sunshine which raises the soil temperature and accelerates the destruction of the organic matter. Destruction is slower in temperate climates, where the sun is not so strong and the temperature is fairly low throughout the year, even in the summer.

Leaching. Leaching is the washing of mineral salts from the upper to the lower layers of the soil by rain. In the tropics leaching is particularly common with salts from chalk and limestone (that is, calcium and magnesium carbonates) which are soluble in the acid soil water. This often results in the formation of soils consisting largely of alumina and iron oxide. Such soils are known as *laterite* and are the common red soils in the tropics. When dry, such soils harden into a 'hard pan'. This is a nuisance in agriculture, since aeration is much reduced in such soils.

Soil Erosion. Erosion is the washing-off of the soil from higher to lower altitudes, so that the washed soil is robbed of its fertility. This is quite pronounced in the tropics because in the dry period of the year the land is left almost bare, so that when the heavy rains come they beat directly on the soil. The rain is therefore the chief agent of erosion in the tropics. There are three main types of erosion, depending on the causative factors: superficial or sheet erosion, gully erosion, and wind erosion.

(i) *Superficial or Sheet Erosion.* In this type of erosion, the soil over a slope is eroded uniformly. This is generally done by water. It is increased by removal of vegetation from the soil during cultivation and over-grazing. It is therefore not common in forests.

(ii) *Gully Erosion.* This is erosion by rainfall along narrow paths. It is found along roads, paths, and ditches, and it often widens the ditches and may result in sheet erosion. It is common, for example, to find a single tree standing on a pillar of soil while all the surrounding soil has been eroded.

(iii) *Wind Erosion.* In this case light soils may be carried long distances by the wind. It is a problem in tropical deserts.

Methods of Conserving Soil Fertility

1. Prevention of Erosion. Before attempting to renew the fertility of the soil it is important first to prevent erosion by employing soil-

conservation methods, such as vegetative protection and shade, contouring of sloping ground, or terracing and bunding.

Vegetative Protection and Shade. It is essential for fertility that the soil should be kept covered during the rainy period of the year, by planting a cover crop between crops. The sweet potato is a suitable cover crop, but it is also useful to use a leguminous crop because of its nodules (see nitrogen cycle below) which help to provide more nitrogen in the soil. By covering the ground the cover crops also help to prevent destruction of the humus by the heat of the sun.

Contouring and Terracing. It is usual to prevent soil erosion along hill-sides by ploughing along the contours, that is, across the slope of the hill.

Bunding. This method involves planting weeds to serve as 'wash-stops' in lines across the slope so that the draining water accumulates on them and its speed is reduced.

Shelter-belts. Shelter-belts of trees may be planted to prevent erosion by wind.

2. Conservation of Soil water. During the dry period it is important to conserve the soil water by loosening the soil between the crops by hoeing. This prevents further rise of water by capillarity to the exposed dry surface.

3. Conservation of Humus. Humus is the essential organic (plant) matter broken down by fungi and bacteria to provide the mineral salts needed by plants. It is usually black in colour and its accumulation depends on the presence of air, water, calcium, and warmth. Humus, and hence the essential elements, are best maintained by manuring as well as using suitable methods of agriculture, such as shifting cultivation and rotation of crops.

(*a*) *Manuring.* The soil can be manured in three ways: by adding plant material (plant manure), or the droppings of animals (animal or farmyard manure), or by applying chemical fertilizers, such as superphosphate.

(*b*) *Shifting Cultivation.* In many tropical countries where land is plentiful, the system of shifting cultivation is used by farmers. A given area is cultivated for one or two years, after which it is left to revert to bush while a fresh area is farmed. After some years the original area is farmed again. This method allows the soil to accumulate enough plant food during the fallow period. When the fallow period is as long as five to ten years the system is referred to as an extended bush fallow system.

(*c*) *Rotation of Crops to include Legumes.* In European countries where there is insufficient land available to allow shifting cultivation, the same piece of land has to be farmed from year to year. The method of rotation of crops consists in changing the crop on the same land from year to year, in such a way as to make the best use of the mineral salts in different layers of the soil and at the same time replenish the essential mineral salts at regular intervals by manuring and by planting, say, a leguminous crop plant (to supply nitrogen).

The Nitrogen Cycle in Nature

Nitrogen is extremely important for the plant and there exist under natural conditions various processes by which this element is made

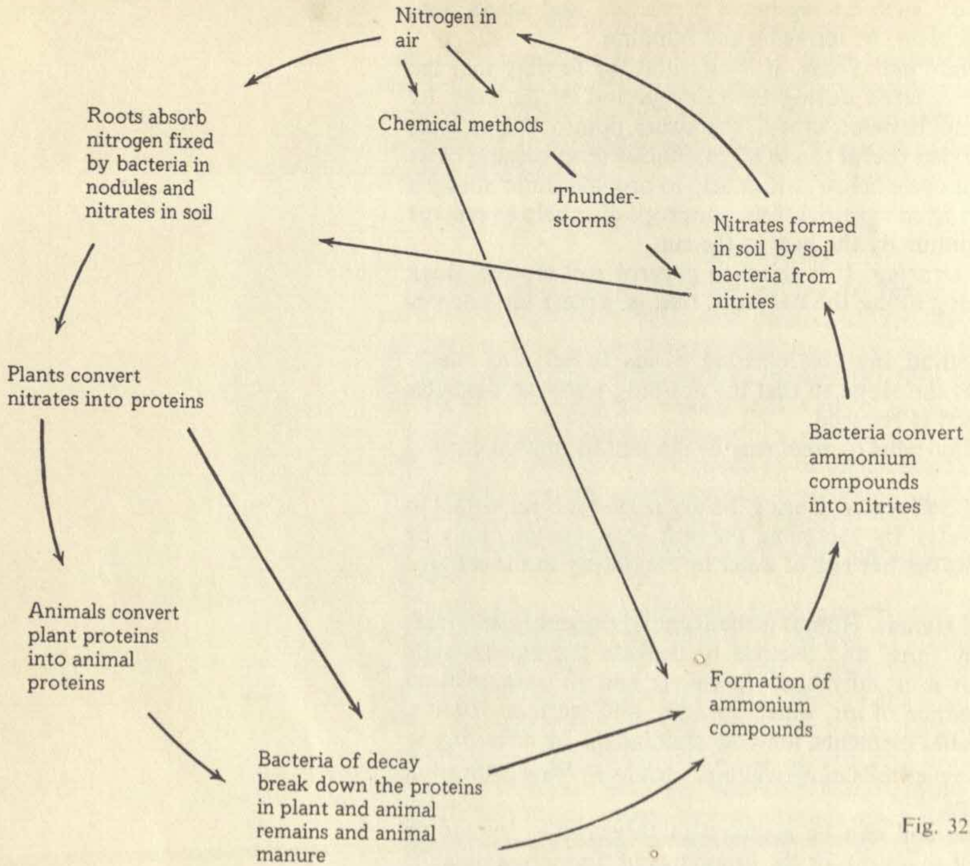


Fig. 32.3. The nitrogen cycle

available to plants and its quantity maintained. In these processes, which make up the *nitrogen cycle* (Fig. 32.3), various bacteria play important parts at different stages.

Nitrogen exists as one of the gases in the air, but this cannot be directly absorbed by plants. Most plants can only absorb nitrogen compounds. Nitrates and ammonium compounds are the chief sources in the soil. Certain *nitrogen-fixing bacteria*, which live in the root-nodules found on leguminous plants (Fig. 2.6), are able to 'fix' (chemically combine) the nitrogen of the air. Thereby they make the nitrogen available to the plant through its roots.

Most of the nitrogen on entering the plant is used to make *plant proteins*. When the plant dies the plant proteins of the humus are subjected to decomposition by *bacteria of decay* and are changed mainly into ammonium compounds. The plant may, however, be eaten by animals which convert the plant proteins into *animal proteins*. The latter are contained in the droppings of the animal—*animal manure*—or in the bodies of dead animals. Both the animal manure and the dead animal material are decomposed, as in the case of the dead plant material. The ammonium compounds in the soil can be increased artificially by using synthetic fertilizers, produced by chemical processes.

In the soil ammonium compounds are acted upon by *soil bacteria* which convert them first into *nitrites* and later into nitrates in the soil. Their quantity in the soil is increased as a result of *thunderstorms* (lightning). During thunderstorms the energy of the lightning discharge causes nitrogen and oxygen to combine to form nitrogen dioxide which dissolves in the rain-drops to form nitric acid. This combines with other elements to form nitrates in the soil. While the roots absorb some of the nitrates, certain bacteria (*nitrogen-freeing bacteria*) reduce the rest to gaseous nitrogen which escapes into the air. These bacteria depend on a high temperature to increase their activity, and this explains why in the tropics it is important not to expose humus to the direct action of the sun. Under such conditions the nitrogen-freeing bacteria increase the quantity of nitrogen in the air.

The nitrogen cycle as described is obviously necessary to maintain the fertility of the soil.

SUGGESTED PRACTICAL WORK

1. Take a sample of soil and determine the amount of air in it, as described in the text.

2. Take another sample of soil and try to determine the amount of water and humus in it, using the methods described in the text.

3. Set up the experiments to compare (*a*) the water-retaining capacity and (*b*) the rise of water by capillarity in sand, clay, and loam.

4. Observe the roots of a number of species belonging to the family Leguminosae, and draw the root-nodules.

5. Work on soils should include an investigation into the activity of earthworms. Darwin estimated that earthworms turned over 11 tons of earth per acre every year, thus helping to maintain soil fertility. Refer again to the practical work suggestions in section 2 (*c*) at the end of Chapter Five.

CHAPTER THIRTY-THREE

Introduction to Heredity

It is common knowledge that we either resemble our parents, our grandparents or someone among our relatives even though we may differ from them in some respects. For many years how this was brought about was not understood, and in 1865 Gregor Mendel provided a basis for an explanation as a result of breeding experiments he performed with different characters of varieties of garden peas. The study of how characteristics are passed on from parents to offspring is what we call *heredity* or *genetics*.

Mendel's Experiments

Mendel worked with about seven different characteristics of the garden pea. One of the experiments he performed was to cross a variety of pea having round seeds with another having wrinkled seeds by fertilizing the ovules of one with the pollen grains of the other. (See 'the parents' in Fig. 33.1.) Mendel knew that the pea flowers were normally self-pollinating and so he had to prevent this by opening the flower buds and carefully removing all the stamens before the stigma was ready to receive pollen. These flowers with the stamens removed (emasculated) were enclosed in muslin bags to prevent insects from interfering. When the stigma of the flower was ripe, he collected pollen from the stamens on a plant of one of the characters and dusted it on to the ripe stigma of the flower of the plant with the opposite character.

He planted the seeds produced from the cross, and observed their seed character when the plants flowered and set fruit. He found that all of the offspring had round seeds. (See First Generation in Fig. 33.1.)

Mendel then self-pollinated the flowers of the offspring by enclosing them in polythene bags to prevent insects from bringing pollen from other sources. When he sowed the seeds which he obtained from this selfing he found that unlike the first cross this time, some of the plants had round seeds while others had wrinkled seeds. In actual fact he

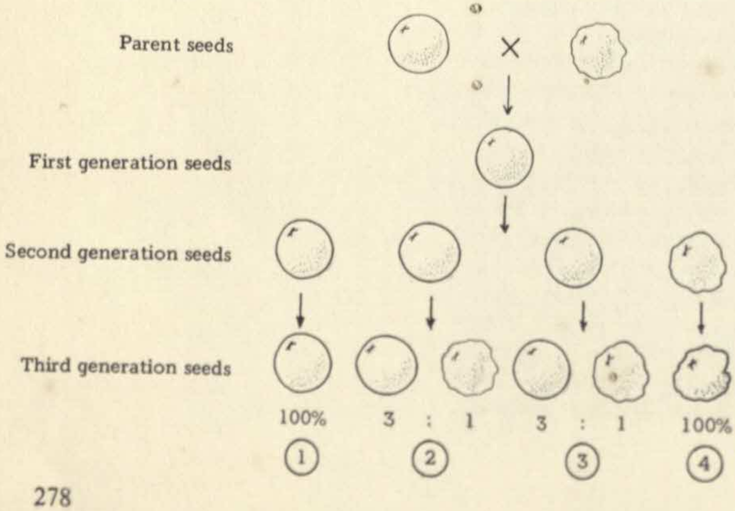


Fig. 33.1. Mendelian inheritance illustrated by a cross between a pure breeding pea with smooth seeds and a pure breeding pea with wrinkled seeds

found about three times as many plants with round seeds as there were plants with wrinkled seeds, i.e. a ratio of 3 round to 1 wrinkled. (See Second Generation in Fig. 33.1.)

Finally Mendel self-pollinated each of the plants bearing the two characters in the second generation. Within the plants with wrinkled seeds he found that all the offspring from selfing also had wrinkled seeds. (See Third Generation 4.) But in the case of plants with smooth seeds the offspring were not uniform. One-third of them produced only plants with smooth seeds (Third Generation 1) while two-thirds produced plants with both smooth and wrinkled seeds in a ratio of 3 round to 1 wrinkled. (See Third Generation 2 and 3.)

From a number of similar experiments Mendel discovered that inheritance of characters depends on certain factors which are passed on from parent to offspring. These factors are now called *genes*, and research has shown that these genes are situated in special structures called *chromosomes* which are found in both plant and animal cells. It is found that during division of reproductive cells the chromosomes behave in a manner similar to the behaviour of the genes as can be inferred from the results of breeding experiments like those of Mendel.

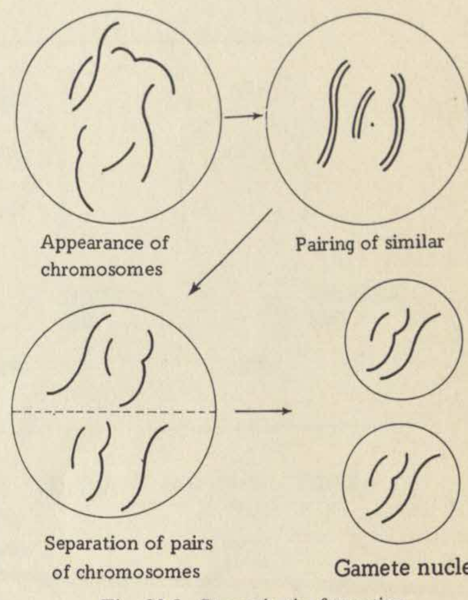


Fig. 33.2. Stages in the formation of sex cells (simplified)

Behaviour of Chromosomes during Formation of Reproductive Cells

It has been found with the aid of the microscope that chromosomes are present in pairs (or duplicate sets) in the body cells of plants and animals. When sex cells (gametes) are being formed from mother-cells it is found that the duplicate pairs of chromosomes separate so that only one set of the chromosomes remain in each sex cell. This is illustrated in Fig. 33.2.

At fertilization however the duplicate set of chromosomes is brought together again from the sex-cells (gametes) of the male and female organisms.

The behaviour of the chromosomes in this respect is found to be the same as the behaviour of the genes which are carried by the chromosomes. In other words, any character such as the seed-coat in the garden pea, is controlled by a pair of genes which separate during the formation of reproductive cells. The separation of genes is referred to as *segregation*.

Because the chromosomes in the body cells are present in pairs, we often represent the factor or gene which controls the character by a double symbol. For example, if we let *S* represent the gene which controls the character of smooth skin of the seeds of the sweet pea, then the proper genetic representation should be *SS*. In the same way the genetic representation for the wrinkled character should be *WW*.

Dominance. Let us now use the above-stated symbols to explain the experiment of Mendel described above. When the plants with smooth seeds (*SS*) were crossed with those with wrinkled seeds (*WW*) all the offspring had smooth seeds. This phenomenon whereby only one of the two characters used in a cross showed up in all the offspring has been observed in various other experiments involving organisms and other characters, and is referred to as *dominance*. The character which showed up in all the offspring was referred to as the *dominant* character,

while the one which was completely marked was referred to as the *recessive* character. Thus in the experiment on seed coat we consider smooth seeds as dominant over wrinkled seeds which were therefore recessive. Examples of tropical plant characters showing dominance includes red and pink colour of the ripe pepper fruit (*Capsicum annuum*).

Some characters show no dominance and this will be explained shortly.

Phenotype and Genotype. The genetic representation of the first cross in the seed coat experiment can be written as follows:

SS	×	WW		Parents
S S	×	W	W	Gametes
SW		SW		Offspring

This shows that although the external appearance of the seed-coat of the offspring is smooth they actually have a genetic composition that is different from that of the original smooth-seeded parents. Thus it is possible in principle to distinguish between the external appearance of a character (referred to as its *phenotype*) and its genetic constitution (referred to as its *genotype*). An individual which has both dominant and recessive genes is referred to as a *heterozygote* (or a *hybrid*) while one with only dominant genes (such as SS) or only recessive genes (such as WW) is referred to as being a *homozygote*. Thus the offspring here are heterozygote dominants.

Absence of Dominance. Some of the breeding experiments that have been carried out by various geneticists since the discovery of the work of Mendel in 1900 show that dominance is not always present and that in some characters the cross between the homozygous dominant and the homozygous recessive, results in a character of the offspring which is not like any of those of the parents but is rather an intermediate one. A good example of this among tropical plants is shown by the presence of the shell in the oil-palm fruits. Here the thickness of the shell varies considerably, but through selection certain forms with large shells and others with practically no shell have been isolated. Experiments have shown that the homozygous dominant (DD) known as 'Dura' with a large shell shows no dominant relationship to the homozygous recessive (dd) called 'Pisifera' with no shell. The cross between these two characters produces plants with intermediate size of shell (Dd) known as 'Tenera'.

When the 'Tenera' heterozygotes are selfed, the next offspring shows one quarter 'Dura' (DD) half 'Tenera' (Dd) and one quarter 'Pisifera' (dd), that is a ratio of 1 Dura : 2 Tenera : 1 Pisifera (Fig. 33.3).

Another example is often found with the flowers of some plants where a cross between those with red and white flowers results in offspring having pink colour. An example of this is the common 'water leaf', *Talinum triangulare*.

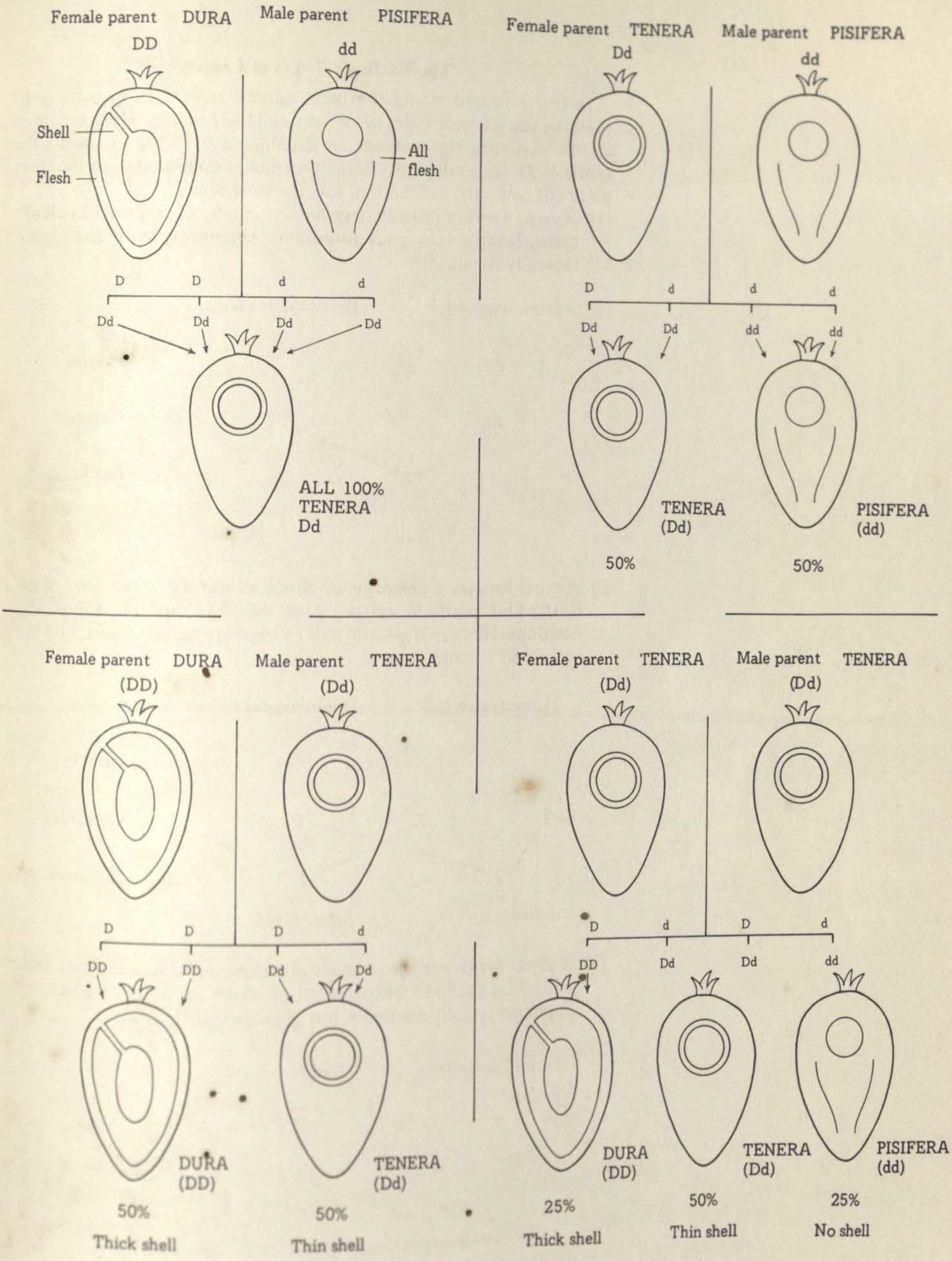


Fig. 33.3. Illustration of crosses in oil-palm breeding

The Six Basic Types of Crosses

In order to understand the basic genetic rules it is instructive to examine the six basic types of crosses and their results. Here we are of course assuming the presence of dominance, and we are using the symbols *TT* for a tall plant character which is dominant over the short plant character (*tt*) as found in, say, the garden pea.

(1) *A cross between two homozygous dominants:* This results in all offspring being homozygous dominant—i.e. genotypically and phenotypically dominant.

Homozygous tall × Homozygous tall

TT *TT* Parents

T *T* Gametes

TT — Offspring

Tall

(2) *A cross between a homozygous dominant and a heterozygote dominant:* This produces offspring *all of which* are phenotypically dominant, but *genotypically* half of them are homozygous, and *the other half* heterozygous.

Homozygous tall × Heterozygous tall

TT *Tt* Parents

T *T* *T* *t* Gametes

TT *Tt* Offspring

Tall Tall

homozygous heterozygous

(3) *A cross between a homozygous dominant and a homozygous recessive:* This produces offspring all of which are heterozygotes, that is phenotypically dominant but genotypically hybrid.

Homozygous tall × Homozygous short

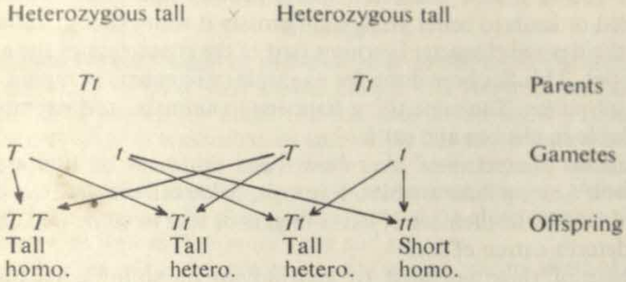
T T *tt* Parents

T *T* *t* *t* Gametes

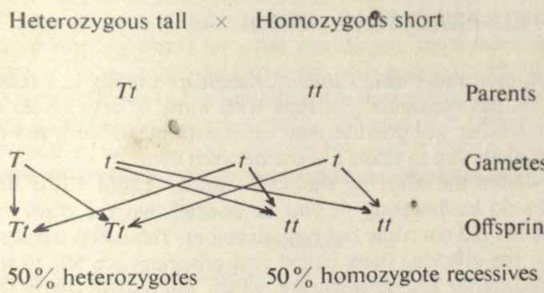
Tt *Tt* Offspring

Heterozygous Heterozygous

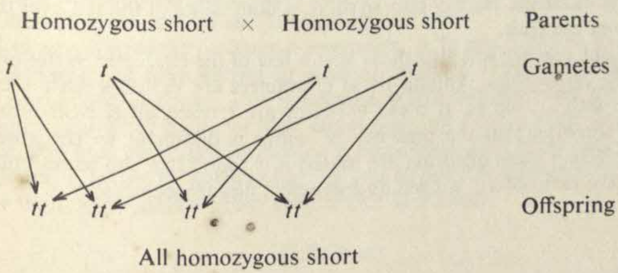
(4) *A cross between two heterozygous dominants:* This produces *offspring* one quarter of which are *homozygous dominant*, half are *heterozygous dominant* and one quarter are *homozygous recessive*, thus giving a phenotypic ratio of 3 : 1 and a genotypic ratio of 1 : 2 : 1.



(5) *A cross between a heterozygous dominant and a homozygous recessive:* This produces offspring with half heterozygous dominant and half homozygous recessive, this giving a phenotypic and genotypic ratio of 1 : 1.



(6) *A cross between two homozygous recessives:* this *produces offspring* all of which are *homozygous recessives.*



Applications of Genetics. It should be stressed that the principles of heredity or genetics are the same for both plants and animals, as well as Man. The amount of information in heredity which has been provided here is very basic and involves the action of single genes. Future

studies will involve not only the operation of more genes at a time, but also the various modifications that occur in the expression of the genes.

Man has exploited the facts of heredity to improve crops and animals to meet his needs. When occasionally a single seed of a particular wild plant shows a new character spontaneously and that character is fancied or leads to better yield, man crosses it with existing varieties so that the desired character becomes part of the characters of the existing varieties. This has been done for example in bananas, mangoes, coffee and oil-palms. The same thing happens in animals, and examples are available in chicken and cattle.

Various characters of Man have been shown to be under genetic control. Among these are blood-groups, sickle cell disease, eye-colour, polydactyly (the presence of extra fingers or toes in some persons) and the determination of sex.

Some of these are used to give advice on suitable partners for marriage, to deduce the parentage of a child in cases of dispute, to help doctors in the diagnosis and treatment of certain diseases.

SUGGESTED PRACTICAL WORK

1. The common water-leaf, *Talinum triangulare* usually has reddish (purplish) flowers, but occasionally a type with white flowers arises spontaneously. Your teacher will provide your class with plants with red and white flowers, and guide you to make a cross between them.

The seeds from the offspring should be sown. Within 40 to 50 days the offspring should be flowering. It will be noticed that the flowers of all of them are neither red nor white but pink in colour. *Talinum* is a self-pollinated plant, and if the offspring (here called first offspring) are left to themselves they will produce the second offspring, which will resolve themselves into a Mendelian ratio of 1:2:1 of red, pink and white-flowered plants, respectively, showing that there is no dominance of the red colour over the white.

2. Where the white-flowered *Talinum* is not available you can perform the above experiment using two varieties of *Capsicum* pepper such as the red and the pink varieties. Here of course there is dominance of the red over the pink colour of the fruit.

3. Your teacher will also show you a few of the character variation in the fruit fly *Drosophila*. Among these characters are varieties with wings and others without wings. If these varieties are crossed all the offspring have wings showing that the presence of wings is dominant to the absence of wings. When these offspring are mated it is found that the second offspring are in the ratio of 3:1 winged and wingless flies respectively.

APPENDIX

How to Answer Biology Questions

Drawings

You are always encouraged to illustrate your written answer with diagrams since they help to make your answer clearer. But you may specifically be asked to draw one or two things. In either case it is advisable to make your drawings as *large* as reasonable. In some cases this may require a half-page drawing, but in others you may have to use a whole page, including the labelling. This provides more room to make your *drawing clearer.* You should make sure that the *shapes* of the parts of the object you are drawing are correct, as well as their *proportions* and *positions.*

One other use of the diagram or drawing is when you are short of time to write out a description. Even in this case it is important to provide *a good-quality* drawing.

Labelling

You must label your drawing fully, and your labelling should show that you understand what you have drawn. Your labelling lines should begin from the correct parts so that it is clear to what part any line refers. You cannot be given any marks for what you draw without labelling.

In some cases, you may be provided with a drawing to label. It is very essential in such cases to label intelligently. For example, if you are to label a drawing of a stage in the germination of a seed, it is better to say whether it is hypogeal or epigeal, and whether the seed is from a dicotyledon or a monocotyledon, rather than to say just that it shows 'a germinating seed'.

Naming

You may be asked to describe a *named* plant or animal, or their parts showing some feature. You may in some cases be asked to describe a phenomenon giving *known examples.* Quite often you have to draw the plant or animal or the part which you describe, and first of all it is essential that the name you give should agree with what you have drawn or described. If you draw, say, a *Canavalia* bean, don't call it a mucuna bean, because the two are different. Also, it is no use just calling it 'a bean'.

When you are asked for known examples, it is much better to mention the examples you have known or studied yourself, rather than those you have read about in books. This is because sometimes you may mention an example which your examiner may know does not exist in your locality. Of course, you may have travelled to see it somewhere else. However, to avoid any doubt, it is usually much easier for you to describe what you have seen, rather than what you have only read about in a book.

Definitions

If you are asked to give a definition of a phenomenon, this should be brief and concern itself with only the essential aspects or meaning. Such questions are meant to find out whether you know the essence of the phenomenon. For example, digestion may be defined as a process by which enzymes make food soluble and ready for absorption or diffusion into the body tissues.

Originality in Answers

A number of the questions in biology are original in the sense that the answer is never presented as such in a book. Therefore you must be prepared to think out your answers to such questions from your overall knowledge of the particular subject. For example, if you are asked to trace the path along which a molecule of oxygen travels from the air into the tissues of the arm, you will realize that you have to think it out yourself. Here the question covers respiration and blood circulation. In this question you should describe first of all the path of oxygen till it reaches the alveoli, then its diffusion in solution into the blood in the capillaries, and how it unites with haemoglobin in the red corpuscle. Then describe its path in the circulation—that is, from pulmonary vein to left auricle, to left ventricle, to the aorta, to a branch artery, to the capillaries of the arm—and diffusion to the tissue.

Even where the answer is often stated in the textbook, a student is expected to add to this if he knows of more facts from other parts of his studies. To illustrate, let's take a simple question like the functions of the root. The usual ones found listed in text-books are (*a*) absorption of water and salts, (*b*) holding the plant, and (*c*) storage in some cases, as in root-tubers. But a little effort will bring to your mind the fact that in say, mangroves, the roots are used for breathing. It is also a fact that the roots also conduct downwards the carbohydrates prepared higher up the plant. Finally, it is correct to say that among what the roots absorb from the soil is oxygen in solution.

Comparisons

It is common to be asked to compare two organisms or phenomena. In particular such questions often centre around differences between plants and animals, or their parts, both in their structure and physiology. Apart from the basic differences known in general terms to exist between plants and animals, there is often a need for originality since parts of a specific plant may be compared with those of a specific animal, such as *Spirogyra* and *Hydra*, or a named flowering plant and *Hydra*.

The mode of nutrition is often the central difference which you must not forget to treat in reasonable detail. In fact, similar comparative questions are often set involving two plants where one of them is a fungus such as *Mucor* or *Rhizopus*. Here again the peculiar mode of nutrition in the fungus should be clearly brought out in the answer.

As stated above, sometimes the objects to be compared are such that a very original approach and careful thinking out is needed. For example, if you are asked to compare, say the epidermis of a plant with the skin of a mammal, the first fact to realize is that the epidermis of a plant is only a single layer of cells whilst the skin of a mammal is quite a composite structure several cells in thickness. Apart from both being protective and waterproof, they have quite a number of differences which you can make out only after a slow and systematic comparison of their parts.

In general, it is advisable to tabulate your points of similarity and difference, so that you cover the essential features point by point.

Logical and Systematic Presentation of Answers

Certain questions are framed to test your ability to think in a logical and orderly way when providing a suitable answer. Let us assume, for example, that you are asked to show how we see a ray of light. Your answer will have to be systematic and logical, and should include such points as: light ray enters the transparent cornea; the pigmented parts of the iris restrict it; it then passes through the pupil to the lens which transmits it through the

aqueous humour and the vitreous humour, all of which help to produce a sharper image, which is inverted, on the back of the pigmented retina, its sharpness aided also by the pigmented choroid; the sense cells of the retina, mostly concentrated at the yellow spot, send impulses along the (optic) sensory nerve-fibres to the brain, where the orientation of the image is corrected, and the (optic) motor nerve-fibres carry the impulses outwards to the muscles of the eye to enable us to move our eyes or to focus more clearly.

For another example let us consider a question asking for the processes which enable air to get into the lungs when we breathe in. Here again the following order of the main points will be essential: muscles contract and pull on ribs; ribs rise, and the sternum is raised forwards; diaphragm contracts, flattens, and is lowered; thus volume of thorax increases, pressure inside chest cavity (or pleural cavity) decreases, and therefore air enters.

Ecology—Plants and Animals in Their Environment

Questions on ecology are often relatively easier, and provided you have studied some environment yourself, it should be interesting to answer it since much originality can be displayed. It is important to be able to mention exactly the *place* you have studied, and its *position* in relation to a better-known locality, such as your town. If you should draw a *map* of the area studied, this should be *large* enough to make it clear, and you should give a *scale* to indicate the size of the area. Also if you want to show the distribution of some different plants and animals you should use *symbols* to show them differently. *Name* the plants and animals correctly.

It is often necessary to study the factors of the environment which have some effect on the plants and animals there. In a terrestrial (or land) environment, for example, the following may be studied and should be mentioned in your answer: temperature (maximum and minimum), atmospheric humidity, type of vegetation, seasonal changes, rainfall range, light intensity, wind velocity and effect, nature of the substratum (surface features), soil fertility, porosity and oxygen content, and the effect of each organism on the others present (whether some prey on others, etc.).

An aquatic or water habitat such as a pond is a popular choice for study. In such a case, the following factors may be studied and included in your answer: temperature, light, salinity (that is, the degree of saltiness), water current, depth of water, substratum under the water, rainfall, seasonal changes, the plants and animals and their relationships.

The next aspect of such ecological studies is the adaptations of the plants and animals here (structurally and physiologically) to the environment. These should be properly interpreted, such as the following: the shape of teeth in case of a rodent, the shape of beak and feet in the case of a bird, the presence of aerial roots in the case of plants in waterlogged soil, the possession of hold-fast for organisms to withstand wave action on rocks, reduced chlorophyll in the leaves of plants under shade, asymmetrical shape of trees in windy places, water-storage stems in plants of dry and rocky places, etc.

Answering the Question Asked

It is most essential to understand precisely what is wanted by the question before you start to write or draw. If you are asked, for example, to describe a flower pollinated by an insect, it is no use presenting one pollinated by wind, because it does not answer the question, however nicely you deal with it. You cannot alter the question to suit yourself, and the examiner is at liberty to give you no mark for describing the wrong thing. You must be very careful to avoid such situations.

INDEX

HARRAP

ISBN 0 245 52325 1